FISH RESTORATION PROGRAM

PILOT STUDY PHASE II: RESULTS FROM 2016 GEAR EVALUATION IN THE NORTH DELTA

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FINAL REPORT
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Executive Summary

The Fish Restoration Program (FRP) monitoring team is tasked with developing monitoring plans for tidal wetland restoration sites being built pursuant to requirements in the 2008/2009 Biological Opinions for Delta water project operations. The FRP monitoring team is also tasked with making recommendations for a generalized monitoring framework for tidal wetlands in the Sacramento-San Joaquin Delta and Suisun Marsh. Because there are no established methods for monitoring fish or macroinvertebrates in tidal wetlands in this region, we initiated a pilot study to test multiple methods and determine which to recommend for inclusion in long-term monitoring programs. In Phase I (conducted July-October 2015; see Contreras et al. 2016), the primary goal was to determine which methods were feasible for use in shallow water. In Phase II (January-October 2016; this report), the FRP monitoring team performed a more rigorous evaluation of the most successful methods used in Phase I. The results from Phase II informed sampling in Phase III (currently in progress, spring and summer 2017) and plans for future routine monitoring of wetland restoration projects.

Macroinvertebrates

We tested methods for collecting macroinvertebrates in three areas of the Cache Slough Complex near future restoration sites and existing comparison wetlands. We found significant differences in invertebrate communities across regions and across habitat types that may be useful in planning for habitat heterogeneity on future restoration sites.

In vegetated areas, we compared standard D-frame kick nets swept through the water to leaf packs left on the marsh as colonization substrates. We found sweep nets had consistently higher species richness, were not subject to loss or damage, and were faster to collect. Leaf packs had a lower coefficient of variation when used in emergent vegetation, and could differentiate invertebrate community composition between wetlands; however, they could not be used to distinguish between habitat types within a wetland. Based on this study, we will recommend using sweep nets for collection of macroinvertebrates in all vegetated or complex shallow habitat.

To sample benthic invertebrates, we compared 10cm PVC cores, 23x23 cm ponar grabs, and benthic trawls. The benthic trawl collected a higher catch of fish food organisms, but a lower catch of benthic infauna. PVC cores could only be used in water depth of 1m or less, but were logistically easier than ponar grabs when sampling shallow and vegetated habitats. We recommend using both ponar grabs in deep water and PVC cores in shallow water to sample benthic infauna. Benthic trawls were useful in sampling mobile epibenthic organisms; however, they need further analysis with the oblique and neuston trawls to see which combination of methods will be used long-term.

To sample pelagic invertebrates, we compared benthic trawls with oblique trawls and neuston trawls. Oblique trawls had higher catch of Copepoda and Cladocera, but benthic trawls had higher catch of epibenthic Amphipoda and Gastropoda. Neuston trawls captured more terrestrial fall-out insects, particularly Diptera and Hemiptera. Each type of trawl collected a unique community of macroinvertebrates, but sample size was too low to definitively choose a single technique for future sampling.

Our analysis of leaf pack and sweep net data also helped increase our understanding of macroinvertebrate community diversity across regions and habitat types, supporting broader hypotheses identified in the Tidal Wetlands PWT Monitoring Framework.

Fish

Various fish collection gear types were compared to one another for tidal wetland use in the North Delta. Fish abundance did not differ between gear types, however fish sizes, species composition, and diversity differed between some gear types.

Larval fish collections were compared in and around Liberty Island with surface and oblique trawls. Fish abundance, length, and diversity did not differ between the trawls, however surface trawls collected more fish species. Based on these results, surface trawls are recommended for sampling larval fish.

Littoral habitats were sampled in Liberty Island using the beach seine, cast net, and lampara net. Cast net sampling ceased after a month because no fish were caught and not included for analysis. Fish abundance, length, and composition did not differ between the two gear types; however, the beach seine caught a higher number of Chinook Salmon and Sacramento Splittail. Species diversity was higher with the beach seine. Based on these results, beach seines are recommended to sample tidal wetland littoral habitats.

Channel and open water habitats were sampled in the Lindsey Slough Restoration Area with the Kodiak trawl, lampara net, and otter trawl. Due to the low number of fish caught by the Kodiak trawl, this gear type was not used for analysis. Only total fish abundance was similar between the lampara net and otter trawl. Fish lengths, composition, and diversity differed between the lampara net and otter trawl. Otter trawling caught a wider range of fish sizes and higher diversity of fish. Based on these results, otter trawls are recommended to sample channel and open water habitat.

Contents

Preface

The State Water Project (SWP)/Central Valley Project Joint Operations Biological Opinions from the United States Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) and the SWP Incidental Take Permit for Longfin Smelt from the California Department of Fish and Wildlife (CDFW), required the California Department of Water Resources (DWR) to restore 8,000 acres of tidal wetlands in the Sacramento-San Joaquin Delta (Delta) and Suisun Marsh (USFWS 2008[1]; CDFW (formerly CDFG) 2009[2]; NMFS 2009[3]). Restoration may improve fish habitat and food web resources. In October 2010, CDFW and DWR approved the Fish Restoration Program (FRP) Agreement, which directed DWR and CDFW to work jointly to implement and monitor the required tidal wetland restoration (CDFW and DWR, 2012[4]).

Restored tidal wetlands in the upper San Francisco Estuary need well-designed monitoring programs to monitor benefits to at-risk fish species such as Longfin Smelt, Delta Smelt, and winter- and spring-run Chinook Salmon. Therefore, the FRP monitoring team formed the Interagency Ecological Program (IEP) Tidal Wetlands Project Work Team (PWT) to develop a framework for monitoring diverse restoration sites in a standard manner. The PWT developed conceptual models detailing how at-risk fish may use restored tidal wetland habitat. The conceptual models provided the pathway to develop hypotheses that led to metrics and sampling strategies. Many of the sampling strategies were straightforward, and the PWT included existing standard operating procedures in the framework. However, there was no consensus on the most desirable methods for monitoring epiphytic and epibenthic macroinvertebrates, or fish in tidal wetlands. Therefore, the FRP monitoring team undertook a pilot study to test various gears the PWT recommended.

During Phase I of the pilot study, the FRP monitoring team conducted preliminary trials of many different gear types to see which were feasible for use in tidal wetlands. This report contains the results from Phase II of the pilot study, in which the most successful gear types from Phase I were deployed with greater replication to determine which we would recommend for inclusion in a long-term monitoring program. Phase II also informed plans for Phase III, currently in progress, which will further refine methods, determine necessary levels of replication, investigate comparability with IEP long-term surveys, and develop baseline data for future restoration sites.

Project Objectives

- For each of the gear types and methods investigated, determine whether deployment in shallow open water, vegetated marsh, or narrow channels will produce statistically valid data and be a reasonable use of resources for future long-term monitoring of restoration effectiveness.
- Identify the suite of gear types/methods that will provide the most complete picture of the communities that contain Delta Smelt, Longfin Smelt, and juvenile Chinook Salmon, their prey base, their predators, and their competitors in shallow-water wetland habitats and allow comparisons to existing long-term monitoring programs.
- Gather data on the variability of community composition and catch per unit effort in these habitat types, which will be used to inform sampling design recommended for long-term monitoring.
- Develop very clear and detailed Standard Operation Procedures for each sampling method and sample processing method for inclusion in the IEP Tidal Wetland Monitoring PWT's Framework for Monitoring Tidal Wetlands in the Upper San Francisco Estuary (currently under development, to be posted at http://www.water.ca.gov/iep/about/tidal_wetland_monitoring.cfm).

[1]United States Fish and Wildlife Service (USFWS) (2008). Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). C. a. N. R. United States Fish and Wildlife Service. Sacramento, California, United States Fish and Wildlife Service. 81420-2008-F-1481-5: 396 pages.

[2]California Department of Fish and Wildlife (CDFW) (2009). California Endangered Species Act Incidental Take Permit No. 2081-001-03 on Department of Water Resources California State Water Project Delta Facilities and Operations. Sacramento, CA.

[3]National Marine Fisheries Service (NMFS) (2009). Biological Opinion and Conference Opinion on the long-term operations of the Central Valley Project and the State Water Project. Long Beach, California**:** 844 pages.

[4]California Department of Water Resources (DWR) and CDFW (2012). Fish Restoration Program Agreement Implementation Strategy: Habitat Restoration and Other Actions for Listed Delta Fish. Sacramento, CA, Department of Water Resources and Department of Fish and Game in coordination with the US Fish and Wildlife Service and the National Marine Fisheries Service.

Part I: Macroinvertebrates

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Part I: Macroinvertebrate gear evaluation

Project Component Lead: Rosemary Hartman

Introduction

In the Phase II macroinvertebrate gear evaluation (this study), we evaluated methods of characterizing macroinvertebrate communities that provide food for fish in restored tidal wetlands. We were particularly interested in the proportion of the community that provides food for Endangered Species Act and California Endangered Species Act-listed fishes (Delta Smelt, Longfin Smelt and Chinook Salmon). Macroinvertebrates associated with vegetation and shallow water habitat, such as amphipods and insect larvae, have been historically under-studied in the San Francisco Estuary; however, they provide the majority of salmonid diet in wetlands (Merz 2001; Sommer et al. 2001; Maier and Simenstad 2009; Bottom et al. 2011), and are a component of Delta Smelt diets when smelt occur in areas of high macrophyte production (Whitley and Bollens 2014; Young et al. 2016a).

While mesozooplankton are recognized as the largest component of Delta Smelt diets (Slater and Baxter 2014), and a significant component of salmon diets (Sommer et al. 2001; Tiffan et al. 2014; David et al. 2016), they are not the focus of this study because there are already standard methods for zooplankton sampling in the San Francisco Estuary (Sommer et al. 2001; Hennessy 2009). In this study, we tested several different macroinvertebrate methods to find the most effective methods to be used in concert with standard mesozooplankton trawls in future monitoring programs. Quantifying macroinvertebrates will be necessary to address many of the hypotheses identified in the PWT's Framework that will be addressed at FRP sites. In particular:

- *F3: Form and magnitude of primary production, along with site and landscape attributes, will drive form and magnitude of secondary production.*
- *F4: Pelagic invertebrate (zooplankton) community composition and size structure will change seasonally and affect fish diet.*
- *F5: Increased area of tidal wetlands will increase the contribution of epiphytic, epibenthic, and drift invertebrates to fish diets relative to appropriate temporal and spatial comparison data.*
- *F10: Restoration will result in a net increase of secondary production (zooplankton and other invertebrates) exported from the site, or at a minimum increase access to productivity by making it available at certain times in the tidal cycle.*

While many invertebrate sampling methods have been employed in wetlands around the globe, there is no recognized standard for epibenthic and epiphytic invertebrates. Many methods prioritize diversity and presence of sensitive species (as an Index of Biotic Integrity) rather than biomass or productivity (i.e., Klemm et al. 1990). The FRP is primarily interested in differences in food production over time and between habitats (biomass of taxa that may be consumed by salmon and smelt), rather than presence of sensitive species. Furthermore, because wetlands are a mosaic of different habitat types, we require methods that work consistently across habitat types and across regions.

Based on recommendations from the Tidal Wetland Monitoring PWT Food Web Subteam[1], we tested a wide variety of methods in Phase I. Phase I focused on comparing different artificial colonization substrates (leaf packs, Hester-Dendy disc sets, and mesh scrubbers), to different active methods (sweep nets, neuston trawls, throw traps, and Marklund samplers) in vegetated areas. Based on results from Phase I, we determined leaf packs and sweep nets were the most effective and versatile sampling methods (Contreras et al. 2016). However, it was unclear how comparable they would be across habitat types and across regions.

Benthic infauna are less frequently consumed by smelt; however, benthic and epibenthic invertebrates often have pelagic life stages where they may be consumed by smelt in the water column. Furthermore, juvenile salmonids foraging in wetlands occasionally consume large numbers of benthic annelid worms and Trichoptera larvae in certain situations (though annelids are usually a very small proportion of their diet; David et al. 2016). Other native fish species, such as Sacramento Splittail, rely heavily on benthic invertebrates (Moyle et al. 2004). While they are not currently listed under the Endangered Species Act, Splittail are a CDFW Species of Special Concern, and may be subject to greater conservation efforts in the future. Regardless of food value, the most pressing reason to assess benthic infauna at restoration sites is the potential impact of bivalves on phytoplankton biomass. The invasive clams *Corbicula fluminea* and *Potamocorbula amurensis* have both been implicated in low primary production in wetlands throughout the upper estuary (Brown et al. 2016). If clams invade a tidal wetland restoration site, they have the potential to decrease phytoplankton and zooplankton biomass before it can reach at-risk fishes (Lucas and Thompson 2012). Quantifying benthic infauna will help address Framework hypothesis S2: *Benthic grazer biomass will increase within restoration sites relative to pre-project conditions*.

Benthic infauna have been sampled throughout the estuary using ponar grabs for many years (Thompson et al. 2013; Wells 2015). Smaller corers, which can be deployed by hand, are frequently used instead of ponars in shallow habitat (Howe et al. 2014). These techniques are proven effective in quantifying benthic infauna, but may miss the more mobile epibenthic amphipods that frequently occur in Delta Smelt diets (Slater and Baxter 2014). In Phase I, we compared these three methods, but did not have adequate replication to accurately compare catches. Therefore, we expanded our sampling in Phase II to better compare the catch of mobile epibenthic invertebrates and clams between the gear types.

Results from Phase I:

We conducted the Phase I Methods Trial in August and September of 2015. The primary goal of this first phase was to analyze the logistical feasibility of each of the sample types (see Contreras et al. 2016). We chose methods to include in the second phase of this project based on a combination of logistical difficulty and relative catch observed in Phase I.

Methods that were unsuccessful:

- Hester-Dendy disk sets (catch too low to be representative)
- Mesh scrubbers (catch too low to be representative)
- Throw traps (difficult to use and catch too low to be representative)
- Marklund sampler (difficult to use consistently)

Methods continued or expanded in Phase II:

[1] http://www.water.ca.gov/iep/about/food_subgroup.cfm

- Sweep nets (as used in Toft et al. 2003; Blocksom and Flotemersch 2005)
- Benthic grabs and core samples (Howe et al. 2014; Wells 2015)
- Benthic and oblique invertebrate tows (500 micron mesh as used by IEP long-term monitoring)
- Surface neuston tow (Sommer et al. 2001; Howe et al. 2014)
- Leaf packs (as used in Scatolini and Zedler 1996)

Phase II Study Questions:

1. How do the colonization substrates (leaf packs) compare to sweep nets in collecting a representative community of macroinvertebrates?
2. How does the relative catch of leaf packs and sweep nets change with habitat type?
3. How do benthic cores compare to benthic trawls in quantitatively sampling mobile epibenthic invertebrates?
4. How does the catch of macrozooplankton differ between oblique tows, benthic tows, and neuston tows?
5. How do our proposed sampling gears compare to existing sampling programs?

Each of our study questions focuses on comparing several methods for each type of habitat, and we anticipate that at least one method will be chosen for each habitat type. We assessed each method's ability to characterize invertebrate biomass and community composition with the least time and effort. We will use the results of the pilot studies to select a subset of these methods that provide a comparable, efficient, and representative sample of food production for inclusion in long-term monitoring plans.

Methods:

Sample Location and Timing

We conducted two intensive bouts of sampling, one in mid-March, 2016, and one in early May, 2016. We chose these times to correspond with spawning of Delta and Longfin Smelt, and period of peak residence of juvenile salmonids. The latter time period also corresponds to periods when larval smelt are present in the study region (Sommer et al. 2004; IEP 20 mm Survey). Amphipod and insect abundance tends to be low during this season (M. Young USGS, pers. comm; Howe et al. 2014), but fish of concern are present at their highest densities, and can take advantage of any food resources present.

All samples were collected in the Cache Slough Complex, a region targeted for tidal wetland restoration due to previous studies showing it is an important region for Delta Smelt habitat (Figure I.1; Moyle et al. 2010, 2016). We chose three sites within the Cache Slough Complex to provide a range of variability in potential wetland habitat. One site was in North Liberty Island, on the edge of one of the largest emergent tidal marshes remaining in the Delta. The second site was in Miner Slough and the marsh along the south tip of Prospect Island. This site provides baseline data on invertebrate communities near the Prospect Island Restoration Site. The third site was within the Lindsey Slough Restoration Site, which was restored in the fall of 2014. Sampling this site allows us to observe invertebrate communities immediately following restoration.

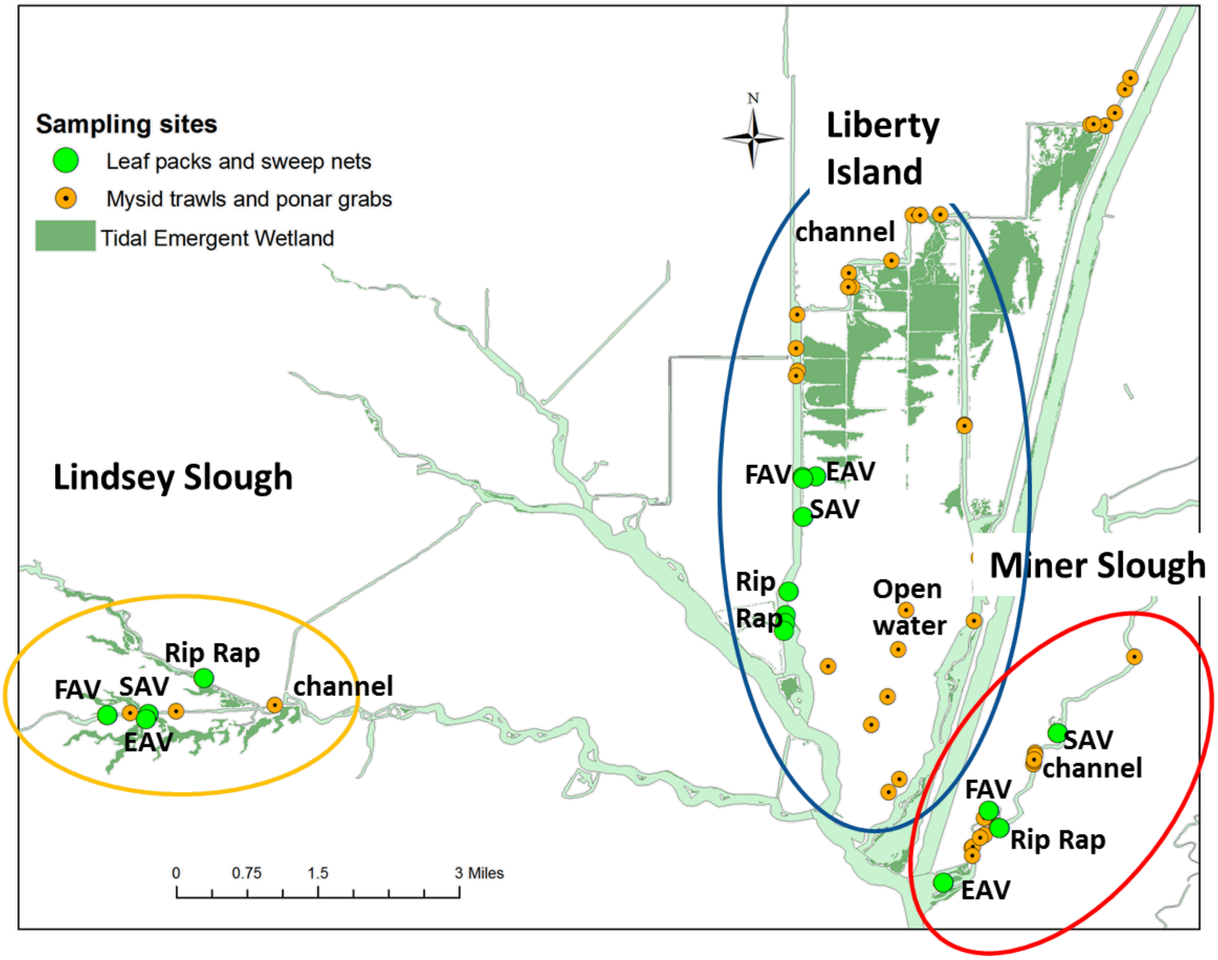


Figure I.1. Sampling regions within the Cache Slough Complex. Each sampling region contained four sampling sites, each with a different habitat type: SAV, FAV, EAV, channel, or rip-rap. Oblique trawls were distributed in channels around the wetland regions.

Description of habitat types:

Habitat type (water depth and presence of vegetation) will impact efficacy of our sampling methods, so we tested methods in four different habitat types (Figure I.2). Not all methods could be applied in all habitats.

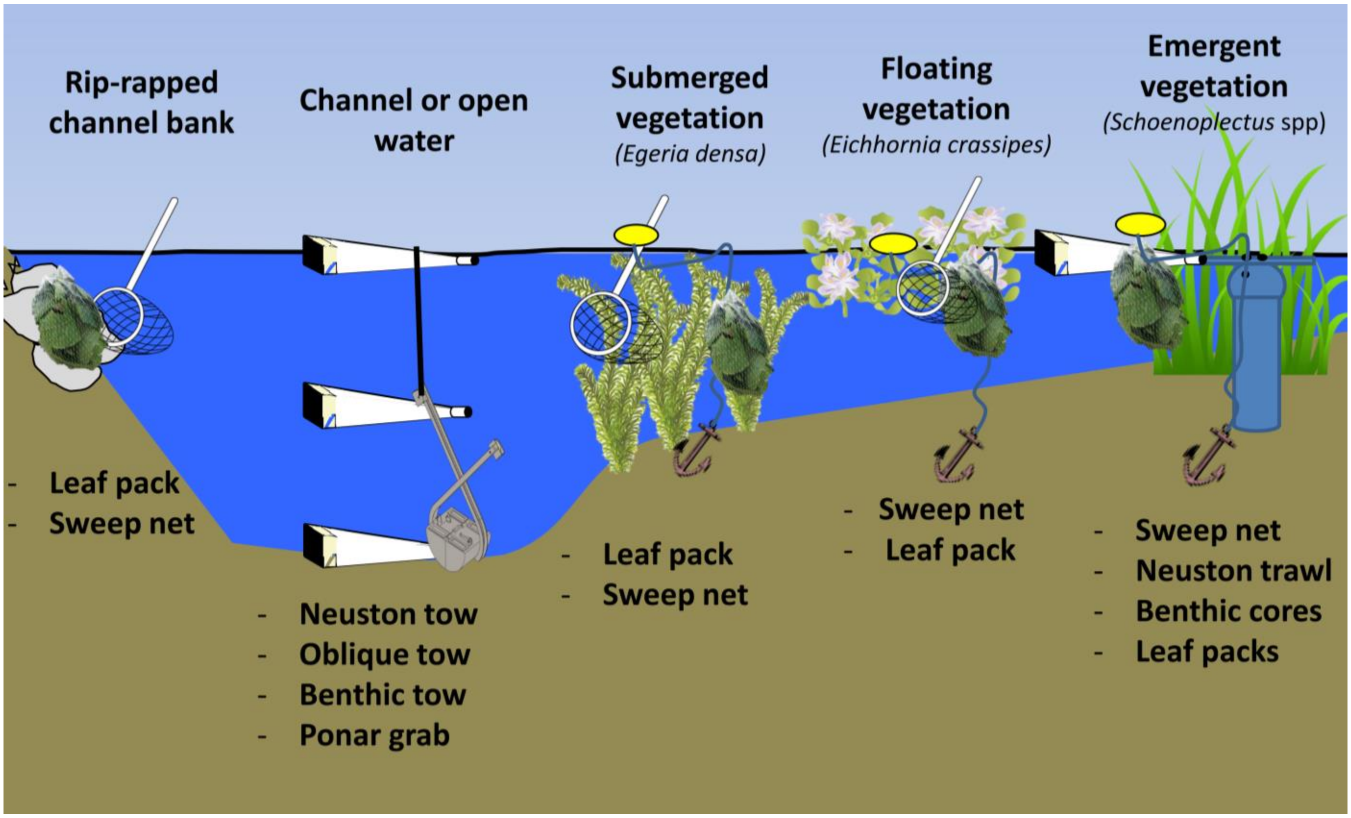


Figure I.2: Habitat types and gear types used during this study.

Emergent vegetation (EAV; 65 samples total): We collected emergent vegetation samples in tules (*Schoenoplectus* spp.), with samples taken within 1m of the vegetated edge. This is the easiest area to sample and where salmonids have been shown to forage most effectively (Simenstad and Cordell 2000). Methods tested in this habitat type: sweep nets, leaf packs, neuston tow (along edge of vegetation), and benthic cores.

Channel and rip-rap (90 samples total): Our channel sampling occurred in major channels outside the vegetated wetlands. Trawling occurred mid-channel, while leaf packs and sweep nets were deployed on rip-rapped channel banks. Methods tested in this habitat type: oblique mysid tow, neuston tow, benthic tow, leaf packs, sweep nets, and benthic cores/ponar grabs.

Submerged Aquatic Veg (SAV; 31 samples total): SAV sampling took place in *Egeria densa*. Submerged vegetation has been implicated as negative for native fish due to high occurrence of invasive predatory fish (Ferrari et al. 2014), but it may also provide high invertebrate production (Boyer et al. 2013). While restoration plans often try to limit establishment of SAV, some SAV will be inevitable in restoration sites. Therefore, quantifying the degree to which it can provide food and habitat will give us a better understanding of the system. Due to sparse vegetation in March, only three SAV sweep net samples were collected in March, and the remaining 12 samples were collected in May. Methods tested in this habitat type: sweep nets and leaf packs.

Floating Aquatic Veg (FAV; 30 samples total): FAV sampling was conducted in dense water hyacinth (*Eichhornia crassipes)*. Little is known about the effect of invasive FAV on fish use or the productivity of wetlands, but one study has shown it to be functionally very different from native FAV (Toft et al. 2003) and it may block establishment of emergent vegetation and submerged vegetation (Khanna et al. 2012). Restoration practitioners try to limit the establishment of FAV, but recent increases in water hyacinth and creeping water primrose (*Ludwigia* spp.) indicate that some FAV establishment in restoration sites is likely. Methods tested in this habitat type: sweep nets and leaf packs.

Table I.1. Number of samples for each habitat type and sampling method. These replicates were designed to be evenly distributed amongst sites and sampling periods, though logistical constraints and sample loss caused an unbalanced design in some cases.

	Number of samples for each method						
Habitat type	Leaf packs	Dip net/ Sweep net	Benthic trawl	Oblique trawl	Neuston trawl	Benthic core/ponar	total
Emergent vegetation	15	18	0	0	17	15	65
Submerged vegetation	16	15	0	0	0	0	31
floating vegetation	13	17	0	0	0	0	30
Open water/channel	16	17	16	10	18	13	90
total	60	67	16	10	35	28	216

Description of Sampling Methods:

For all invertebrate sampling methods, we used 500 micron mesh for nets and sieves to target macroinvertebrates greater than 0.5mm. All samples were preserved in 70% ethanol dyed with rose Bengal to aid in sorting invertebrates from substrate.

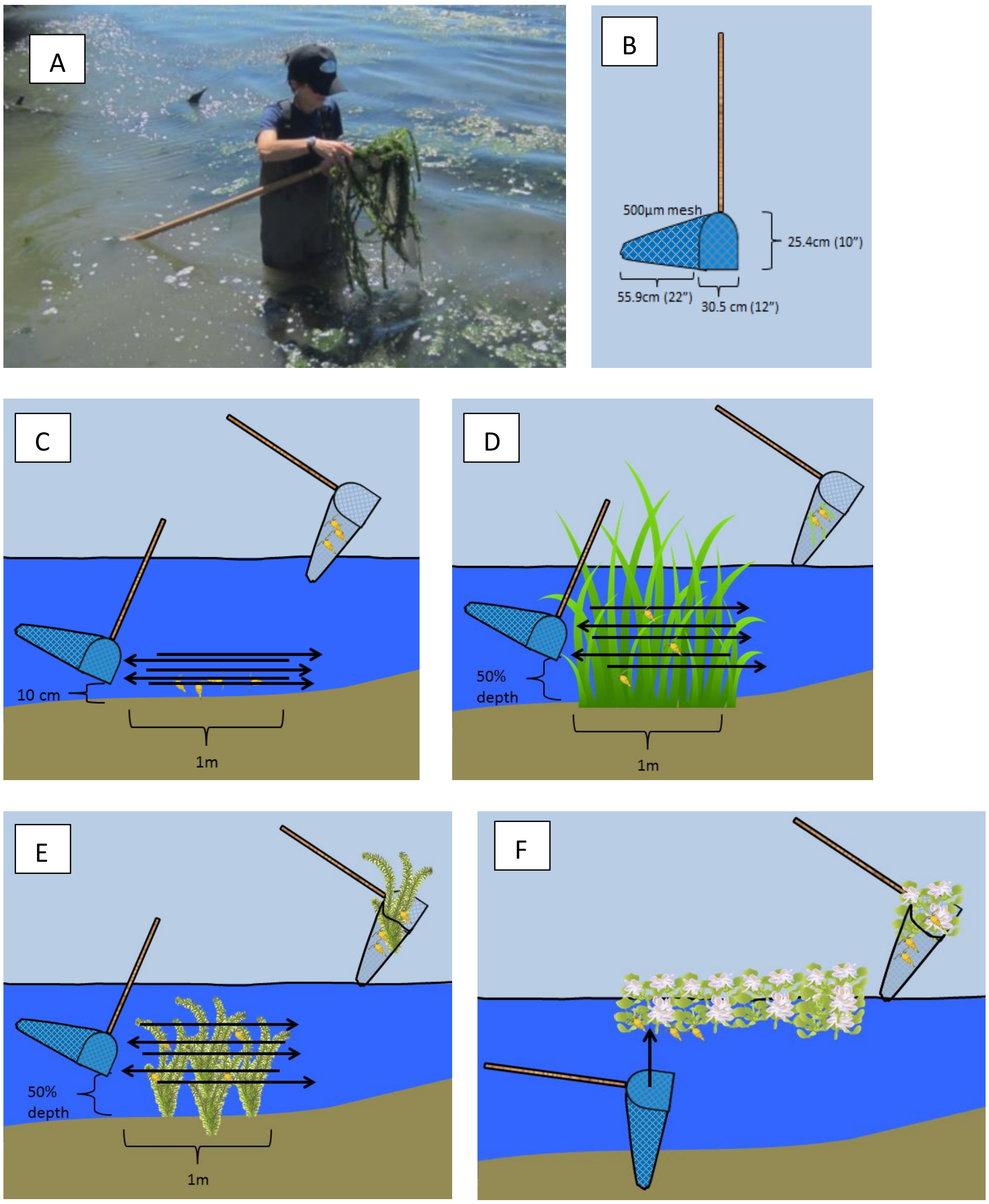
Sweep nets: Sweep nets are a simple but effective way to sample the invertebrate community. Sweep nets may capture higher species diversity than many passive methods, though with higher variability in biomass (Turner and Trexler 1997). We used a D-frame net (mouth area 55.9 x 25.4 cm) with 500 micron mesh for all sweep net samples (Figure I.3A, B). We adapted the sweep net technique slightly in different habitat types.

Channel: In rip-rapped channel banks, we swept the net through the water approximately 3cm above the bottom 5 times (10 seconds of effort) with each sweep being approximately 1m in length (Figure I.3C). We then rinsed down the net and preserved all invertebrates in ethanol for later identification. Catch per unit effort (CPUE) was calculated as invertebrates per sample.

EAV: In emergent vegetation, we conducted the same five one-meter sweeps, but we scraped the vegetation as much as possible to knock invertebrates off the stems (Figure I.3D). We then rinsed down the net and preserved all invertebrates in ethanol for later identification. CPUE was calculated as invertebrates per sample.

SAV: In submerged vegetation, we swept the net five times through the thickest growth of vegetation, and collected any vegetation within the border of the net after the sweep was completed (Figure I.3E). We placed the plant material and associated invertebrates in a bag on ice. Within 48 hours of collection, we rinsed the vegetation, separated the invertebrates, preserved the invertebrates for later identification, and dried the vegetation to a constant weight. CPUE was calculated as number of invertebrates per biomass of vegetation.

FAV: In floating vegetation, we dipped the net to harvest vegetation instead of sweeping through the vegetation. We collected a sample from below with the same sweep net and severed the connection to surrounding plant material with shears (Donley Marineau 2017, Figure I.3F). We placed the roots of the plant material and associated invertebrates on ice. Within 48 hours of collection, we rinsed the vegetation, preserved the invertebrates for later identification, and dried the roots to a constant weight. CPUE was calculated as number of invertebrates per biomass of vegetation.



FigureI. 3. A) R. Hartman using a sweep net in Phase I sampling to collect submerged vegetation and associated invertebrates. We sheared off vegetation outside the frame of the net so only vegetation inside the net was retained. **B)** Specifications of the sweep net. **C)** Use of sweep net in unvegetated habitat and rip rap. **D)** Use of

sweep net in emergent vegetation. **E)** Use of sweep net in submerged vegetation. **F)** Use of sweep net in floating vegetation.

Leaf Packs: In Phase I of the pilot study, we tested a variety of passive substrate traps to collect a standard amount of invertebrates in emergent vegetation. We found leaf packs to be the most effective (Contreras et al. 2016). These are commonly used for stream systems, but are also used in wetland and estuarine systems where there is extensive emergent vegetation (Whitfield 1989, Scatolini and Zedler 1996, Warren et al. 2001, Fig. 5).

To construct the leaf packs, we harvested tules (*Schoenoplectus acutus*), removed any invertebrates and sediment, and dried them to a constant weight in a drying oven at 60^{o}C. We placed 30g of dried stems (each approximately 15cm in length) in a labeled, plastic mesh bag (Figure I.4). Each leaf pack was attached to a line and tied to a float. Each line was attached to a separate anchor and set at least 5m apart. Samplers were suspended mid-way in the water column in vegetated habitats, and staked on the bottom in unvegetated habitats. We set the first batch of leaf packs out in the wetland in early February so that they would be collected at the same time as the sweep nets during the first collection bout in mid-March.

After approximately six weeks, we harvested the leaf packs by carefully surrounding them with a net (to prevent escapees), and removing the samplers from the buoy. Upon collection, we placed the entire leaf pack on ice for return to lab. Within 48 hours of collection, chilled leaf packs were disassembled and rinsed to remove any invertebrates. Invertebrates were preserved in ethanol for later ID. We calculated CPUE as number of invertebrates (n) per gram initial weight of vegetation (mv).

CPUE = n/ m_v.

Figure I.4. Leaf packs constructed of mesh bags filled with 30g dried *S. acutus*.

Benthic core: Benthic cores have been used extensively to quantify chironomid and amphipod populations, as well as bivalves and other infauna in tidal wetlands (Wells 2015, Howe et al. 2014, CDFW unpublished data). While many chironomids and amphipod life stages present in fish diets are pelagic (S. Slater, pers. comm.), they also have benthic life stages. In shallow water (<1.5m), we took a 4in (10cm) diameter benthic core (figure I.5A), hand-deployed to a depth of 20cm. In deep water (>1.5m), we used a 9 x 9in ponar grab modified for use in hard substrates (as per USFWS Liberty Island Monitoring, L. Smith pers. comm., figure I.5B), with three samples at each site. The core was washed and sieved on board the boat to remove the sand/mud and preserve any organic detritus and invertebrates. We CPUE as number of invertebrates (n) per surface area of substrate sampled (A). The area of the ponar grab is 0.052m², and the area of the PVC core is 0.0081m².

CPUE = n/A

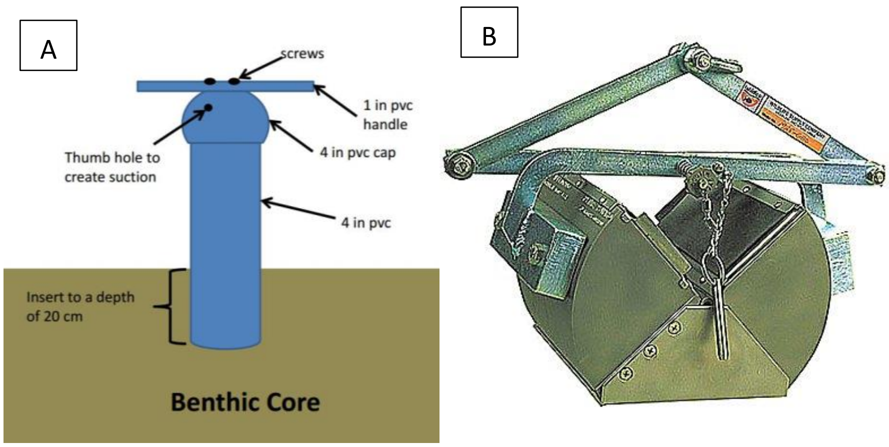


Figure I.5. A) Benthic core made of 4 in PVC pipe for use in shallow water (<1.5 meters). **B)** Ponar grab for use in water greater than 1.5 meters.

Mysid Nets (oblique and benthic tows): Mysid nets have been used extensively to characterize water column macrozooplankton such as amphipods and mysids that are large components of fish diets (Feyrer et al. 2003, Slater and Baxter 2014). We sampled macrozooplankton in the water column during daylight using a 40cm x 40cm mouth (0.500mm mesh size) mysid net mounted on a sled (Figure I.6; similar to EMP methods, Hennessy 2009). This is the same net used for larval fish sampling, so oblique tows were combined with larval fish sampling to reduce effort and potential take (see Chapter 2). A General Oceanics flowmeter was mounted in the mouth of the net to measure volume of water sampled. The gear was deployed behind the boat with a buoy attached and sampled obliquely through the water column at 1-2mph for ten minutes. The same sled was towed along the bottom for five minutes during benthic tows. After retrieval, the net was rinsed from the outside to wash down the sample into the cod end. All contents collected in a cod end were preserved in 10% buffered formalin (oblique tows, combined with larval fish) or 70% ethanol (benthic tows, invertebrates only) for later ID.

On a subset of the oblique tows, a 150 micron mesh mesozooplankton net was fixed to the side of the mysid net. Mesozooplankton were not the target of this study, but collecting some mesozooplankton allowed us to establish baseline data for zooplankton in the area, and allowed our lab staff to gain experience identifying zooplankton to a finer level of taxonomic resolution.

We calculated CPUE for trawls by number of invertebrates (n) per cubic meter of water sampled, as derived from the flowmeter readings and the mouth area (A) of the net.

CPUE = n/((v2 – v1)*k*A),

where v2 = end flowmeter reading, v1 = start flowmeter reading, k = flowmeter factory calibration factor.

Figure I.6. Set up of oblique and benthic sled for mounting mysid and zooplankton nets.

Neuston tow: Emerging insects and collembola found at the surface of the water are an important feature in salmonid diets, and are commonly sampled using neuston tows and drift nets (Sommer et al. 2001, Howe et al. 2014). The neuston net is a 45cm x 30cm rectangular net, 1m long with 0.500mm mesh and is trawled half-way out of the water and sample invertebrates on the surface of the water (Figure I.7). We towed the neuston net at the surface of the water from the side of the boat via a boat hook for three minutes. We standardized effort by the distance of the tow (d) calculated by GPS track multiplied by width of net (0.45m) to calculate surface area of water sampled. After retrieval, all content collected in a cod end was preserved in 70% ethanol for later ID.

CPUE = n/ (0.45m*d)

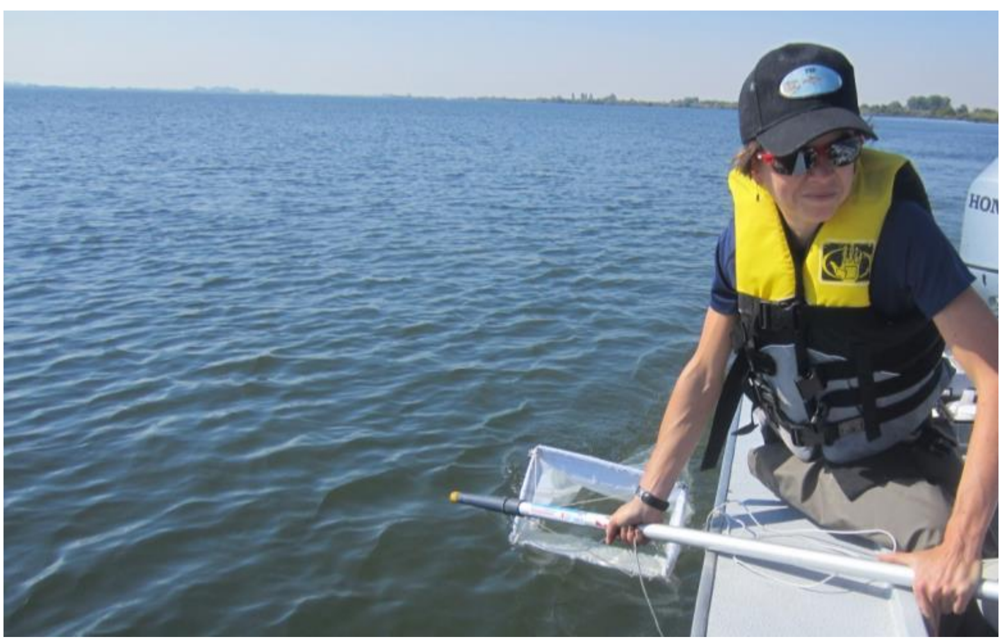


Figure I.7: Deploying the neuston net off the side of a boat.

Laboratory Methods:

Subsampling: If less than 400 individuals were present in a sample, the entire sample was identified. If more than 400 invertebrates were present in a sample, or more than four hours were required for processing, they were quantitatively sub-sampled using a grid tray. Results were expanded to estimate the contents of the entire sample.

Taxonomic effort: Invertebrates were sorted to taxonomic level according to their importance in fish diets and the food web (see Table I.2). Mesozooplankton, such as Copepoda and Cladocera were identified to Order and enumerated when they occurred in our macroinvertebrate samples. Future mesozooplankton sampling will identify them to genus.

Table I.2. Levels of taxonomic resolution recommended for each group of taxa commonly found in invertebrate samples. Taxa marked as "Fish Food" commonly occur in salmon and/or smelt diets and were treated as such in subsequent analyses.

Phylum	Subphylum	Class	Order	Level of ID	Fish food
Annelida		all	all	Class	
Arthropoda	Chelicerata	Arachnida	all	Class	X
Arthropoda	Crustacea	Maxillopoda: Copepoda	all	Order	X
Arthropoda	Crustacea	Malacostraca	Amphipoda	Genus	X
Arthropoda	Crustacea	Malacostraca	Cumacea	Class	X
Arthropoda	Crustacea	Malacostraca	Decapoda	Genus	X
Arthropoda	Crustacea	Malacostraca	Isopoda	Genus	X
Arthropoda	Crustacea	Malacostraca	Mysidea	Genus	X
Arthropoda	Crustacea	Branchiopoda	Cladocera	Order	X
Arthropoda	Crustacea	Ostracoda	Podocopida	Order	X
Anthropoda	Hexapoda	Collembola	All	Class	X
Anthropoda	Hexapoda	Insecta	All	Family	X
Mollusca		Bivalvia	All	Genus	
Mollusca		Gastropoda	All	Family	
Nematoda		All	All	Phylum	
Platyhelminthes		All	All	Phylum	

External Data:

To calibrate our methods and assess how comparable they are to existing sampling programs, we leveraged data collected by the Interagency Ecological Program (IEP), which collects a variety of environmental samples throughout the upper San Francisco Estuary.

Benthic samples: IEP's Environmental Monitoring Program (EMP) takes monthly benthic grab samples using the same size ponar dredge used by the FRP program ($0.052m^2$). The contents of each grab sample were washed over Standard No. 30 stainless steel mesh screen (0.595mm openings, slightly wider than FRP method). Each sample is carefully washed with a fine spray to remove as much of the substrate as possible. All material remaining on the screen after washing is preserved in a solution of approximately 20% buffered formalin containing Rose Bengal dye for laboratory analysis. All benthic invertebrates are identified to genus or species where possible, and all planktonic or terrestrial organisms are discarded. Full data and metadata on the EMP benthic sampling program is available here: http://www.water.ca.gov/bdma/meta/benthic.cfm

To increase comparability, all taxa identified by the EMP were categorized based on our lowest level of taxonomic resolution. EMP's sampling occurs in a broad salinity range, so a subset of their 2015 data from the freshwater region of the Delta (Table I.3) was used, in order to include the most recent species introductions and drought conditions.

Table I.3. The EMP benthic sampling stations from the freshwater reaches of the Delta used for comparison to our catch. Data is available online here: http://www.water.ca.gov/iep/products/dataportal.cfm

Station No.	Location description	Latitude	Longitude
C9-L	Old River upstream of Clifton Court Forebay Intake	37.8271721	-121.5522898
D7-C	Grizzly Bay at Dolphin near Suisun Slough	38.1171292	-122.0395539
D4-L	Sacramento River @ Sherman Island Upstream of Point Sacramento	38.0581151	-121.8193499
D16-L	San Joaquin River at Bradford Island	38.0930310	-121.6697445
D24-L	Sacramento River downstream of Rio Vista bridge	38.1547193	-121.6814495
D28A-L	Old River upstream of Rock Slough	37.9701652	-121.5741188

Surface Invertebrates: The California Department of Water Resources' Aquatic Ecology Section collects drift invertebrates from one location on the toe drain of the Yolo Bypass, approximately one kilometer upstream of our Liberty Island sampling site (Latitude 38.353461, Longitude 121.528083; CDWR, 2016). They sample with an identical net to our neuston net, so catches are highly comparable; however, they do not enumerate zooplankton collected by the neuston net. These samples have been taken at least monthly since 1998, with higher frequency during high flow events. We qualitatively compared community composition based on total catch. This allowed us to assess applicability of this dataset for more quantitative comparisons in future studies.

Pelagic Invertebrates: The EMP's Zooplankton Survey samples for mysids at sites throughout the main channels of the upper estuary. The Fall Midwater Trawl (FMWT) also samples for mysids at a subset of their sampling sites from September through December. Both surveys use 505 micron mesh net with a mouth diameter of 28cm and the length 1.48m. The 505 micron mesh is comparable to our 500 micron benthic and oblique trawls; however, both surveys only quantify catch of mysids and amphipods, not other invertebrates. We compared our catch of mysids to EMP's catch of mysids from 2015 and 2016, and FMWT catch of mysids and amphipods from 2012, from a select set of stations in the freshwater reaches of their sampling area (Table I.4).

Table I.4. IEP's Environmental Monitoring Program Zooplankton Study stations and Fall Midwater Trawl stations in the freshwater reaches of the Delta used to compare catches of mysids and amphipods. Data is available here: http://www.water.ca.gov/iep/products/dataportal.cfm

Program	Station No.	location description	latitude	longitude
EMP	NZ064	Sacramento River at Edmonton (upstream of lights 13 & 14).	38.08472	121.7381
EMP	NZ074	San Joaquin River at Antioch Ship Canal (between lights 7 & 8).	38.02222	121.8036
EMP	NZ086	San Joaquin River at Potato Point (light 53).	38.07778	121.5703
EMP	NZD16	San Joaquin River at Twitchell Island. Core station, replaced NZ080 in 1994 (core 1994-present).	38.09722	121.6667
FMWT	704	Sacramento River - 1300 yards upstream of Lights 11 & 12	38.04252	121.46735
FMWT	706	Sacramento River - upstream of Lights 15 & 16	38.05418	121.44400
FMWT	707	Sacramento River - upstream of Lights 19 & 20	38.06838	121.42478
FMWT	711	Sacramento River - 600 yards upstream of Light 36	38.10557	121.40217
FMWT	716	Cache Slough - N. of cable Ferry 1 & 51	38.14272	121.41063
FMWT	719	Sacramento Deep Water Ship Channel - between Lights 59 & 60	38.20057	121.38840
FMWT	721	Cache Slough - 75 yards S. of Pumphouse on West Bank	38.16089	121.42166
FMWT	723	Sacramento Deep Water Ship Channel - between Lights 51& 52	38.14169	121.40409
FMWT	795	Sacramento Deep Water Ship Channel - between Lights 75 & 76	38.32262	121.35081
FMWT	796	Sacramento Deep Water Ship Channel - between Lights 71 & 72	38.28432	121.35064
FMWT	797	Sacramento Deep Water Ship Channel - between Lights 65 & 66	38.24277	121.36936
FMWT	802	San Joaquin River - 500 yards N. of Point Beenar	38.02117	121.50325
FMWT	804	San Joaquin River - 600 yards upstream from Light 8	38.01385	121.47921
FMWT	809	San Joaquin River - near Light 24 at Jersey Point	38.03072	121.41583
FMWT	812	San Joaquin River - upstream from Light 34	38.05275	121.38930
FMWT	815	San Joaquin River - at junction with Mokulumne River	38.05478	121.34552
FMWT	906	San Joaquin River - between Lights 5 and 6	38.03247	121.30992
FMWT	910	San Joaquin River - E. of S. tip of Spud Island	38.00137	121.27022
FMWT	912	San Joaquin River - near mouth of Calaveras River	37.58130	121.22303
FMWT	919	Little Potato Slough - 1200 yards N. of junction W. White Slough	38.06343	121.29715

Analysis:

We calculated catch-per-unit-effort (CPUE) for each sample, and grouped generic and specific classifications into larger taxonomic groupings (Order or Class) to aid analysis (see Appendix A for most common taxa contained within these groupings). All terrestrial invertebrates were grouped into a single "terrestrial" classification.

To answer Phase II Study Questions 1 and 2 on the differences between sweep nets and leaf packs, we compared total catch and taxon richness of these two sampler types across habitat types and across regions using generalized linear mixed models (GLMs), with the predictor variables listed in Table I.3. Modeling total catch allows us to compare invertebrate production between sites, whereas modeling species richness allows us to compare which sampler gives a more accurate prediction of total species richness. We tested the fit of all possible models and their first-order interactions using Akaike's Information Criterion corrected for small sample sizes (AICc; Anderson 2008; Gotelli and Ellison 2012) and assessed the top model. Data were log-transformed where necessary to meet assumptions of normality and homogeneity of variance. We used binomial mixed models with sample ID as a random effect to test which sampling type had a greater proportion of the catch comprised of organisms that commonly occur in fish diets.

To detect differences in community composition, we used non-metric multidimensional scaling (NMDS) to visualize degree of overlap between communities, and permutational multivariate analysis of variance (PERMANOVA) using the same set of predictor variables to test for statistical differences in community composition (Table I.5). We used a similarity percentages (SIMPER) analysis to see which taxa drove any observed differences between regions and habitat types.

Table I.5. Potential predictor variables for explaining observed differences in catch and species richness for leaf packs and sweep nets.

Variable	Description
Region	Region of the Cache Slough Complex as shown on Figure I.1 (Lindsey Slough, Liberty Island, or Miner Slough)
Habitat type	Tule marsh (EAV), SAV, FAV, or rip-rapped channel bank.
Sampler type	Leaf pack or sweep net
Month	March or May
E(Site)	Specific sampling location, used as an error term to prevent pseudoreplication.

To answer Phase II Study Question 3 on the difference between benthic cores and benthic tows, we compared species richness between our samples and EMP's ponar grab samples using GLMs. Because CPUE is calculated differently for trawls (volume) than for benthic cores and ponars (surface area), we only compared CPUE between the ponar grabs and PVC cores. Data were tested for assumptions of normality and homogeneity of variance, and we used Poisson distributions or transformed the data where necessary to meet these assumptions. When data did not meet these assumptions after transformation, Kruskal-Wallace tests were used instead. Because of the relatively small sample size, we did not have enough statistical power to assess differences between regions or habitat types. We used binomial models to test which sampler type had a greater proportion of the catch comprised of organisms that commonly occur in fish diets. To detect differences in community composition, we used NMDS to visualize degree of overlap between communities, and PERMANOVA to test for significance of observed differences. We used a SIMPER analysis to see which taxa drove any observed differences between sampler types.

To answer Phase II Study Question 4 on the difference between benthic tows, oblique trawls, and neuston tows, we compared species richness between the three sample types using GLMs. Because CPUE is calculated differently for neuston tows (surface area), versus oblique and benthic trawls (volume), we only compared CPUE for the oblique and benthic trawls. Data were log-transformed or modeled with a Poisson distribution where necessary to meet assumptions of normality and homogeneity of variance. When data did not meet these assumptions after transformation, Kruskal-Wallace tests were used instead. We used binomial models to test which sampler type had a greater proportion of the catch comprised of organisms that commonly occur in fish diets. Because of the relatively small sample size, we did not have enough statistical power to assess differences between regions or habitat types. To detect differences in community composition, we used NMDS to visualize degree of overlap between communities, and PERMANOVA to test for significance of observed differences. We used a SIMPER analysis to see which taxa drove any observed differences between sampler types. We compared catch of amphipods and mysids from IEP's surveys to our surveys using zero-inflated Poisson models to account for large numbers samples with no catch. This method models the probability of zero catch (using a binomial model) separately from the size of the catch (Poisson model; see Jackman et al. 2015).

All statistical tests were performed in Program R (R Foundation for Statistical Computing) using packages lme4 (Bates et al. 2016), pscl (Jackman et al. 2015), and vegan (Oksanen et al. 2016).

Results

Leaf pack versus sweep net comparison

We deployed 72 leaf packs, evenly distributed amongst regions and habitat types. We lost 12 of these leaf packs, due to vandalism, high flows, or stranding above the high water mark. This left us with a total of 60 leaf packs, for an 83% recovery rate. We collected 67 sweep net samples. We were unable to collect some of our vegetation samples in March due to low abundance of aquatic vegetation. However, of the samples we collected, we only lost one sample (due to investigator error), giving us a 98.5% recovery rate for sweep nets. Sweep nets only required a single trip to the field, and do not require assembly ahead of time, making them a considerably lower investment in staff field time.

Sweep nets had a higher coefficient of variation in total catch than leaf packs (1.53 versus 1.17). This made it difficult to directly compare total catch between leaf packs and sweep nets because variances were not homogeneous. However, a Kruskal-Wallace test shows that total catch is not significantly different (H value = 0.087, p = 0.767).

Log-transformed total catch better met the assumptions of a linear model. When ranking all possible models of log-transformed total catch, the highest ranked model (delta AICc > 2) included only region and habitat type (Table I.7A). There was much less support for models including sample type, month, or interactions between sample type and target. In particular, floating and submerged vegetation samples had higher catch than channel and emergent vegetation samples (Figure I.9), and catch in Lindsey Slough was higher than Liberty Island and Miner Slough.

A binomial model of proportion of fish food organisms found leaf packs had significantly lower catch of fish food organisms (Figure I.8A, Table I.7B). Lindsey Slough had a lower proportion of fish food organisms than Liberty or Miner, and SAV had a lower proportion than channel and emergent vegetation (Figure I.8B, Table I.7B).

Table I.7. **A)** Coefficients for top ranked model predicting total invertebrate catch of sweep nets and leaf packs. Only region and habitat type were included in the top model; sample type and month were not supported. Top Model: log(Catch) ~ Region + Habitat; Residual standard error: 1.042 on 40 degrees of freedom (DF); Multiple R-squared: 0.4113, Adjusted R-squared: 0.3377; F-statistic: 5.589 on 5 and 40 DF, p > F: 0.0005. **B)** Coefficients for top ranked binomial model predicting proportion of invertebrates that occur in at-risk fish diets. Region, habitat type, and sampler type were included in the top model; month was not supported. Top Model: Null deviance: 6009.8 on 45 DF, residual deviance: 4912.5 on 41 DF.

A) Linear model of total catch				
Factor	Estimate	St. Error	t value	p value
Intercept (channel, Liberty)	4.844	0.372	13.023	<0.001**
Habitat: EAV	0.271	0.425	0.638	0.527
Habitat: FAV	1.431	0.435	3.287	0.002**
Habitat: SAV	1.501	0.435	3.448	0.001**
Region: Lindsey	0.934	0.375	2.493	0.017*
Region: Miner	0.044	0.382	0.115	0.91
B) Binomial model of fish food				
Factor	Estimate	Std. Error	z value	p value
Intercept (leaf pack, channel, Liberty)	-0.478	0.153	-3.119	0.002**
Sample Type: Sweep net	0.363	0.114	3.181	0.001**
Habitat: EAV	0.099	0.161	0.616	0.538
Habitat: FAV	-0.239	0.163	-1.464	0.143
Habitat: SAV	-0.564	0.161	-3.495	<0.001**
Region: Lindsey	-0.709	0.137	-5.188	<0.001**
Region: Miner	0.173	0.143	1.214	0.225

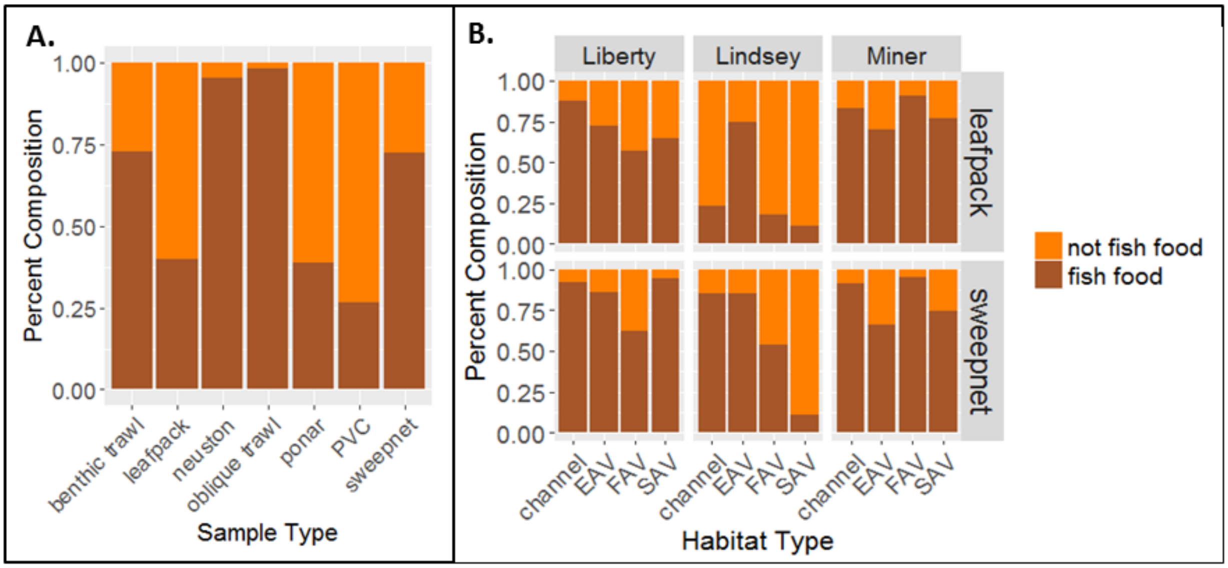


Figure I.8 A) Percent of total catch comprised of invertebrates regularly found in diets of salmon or smelt. **B)** Percent of total catch comprised of invertebrates regularly found in diets of salmon or smelt for leaf packs and sweep nets, divided by habitat type and region.

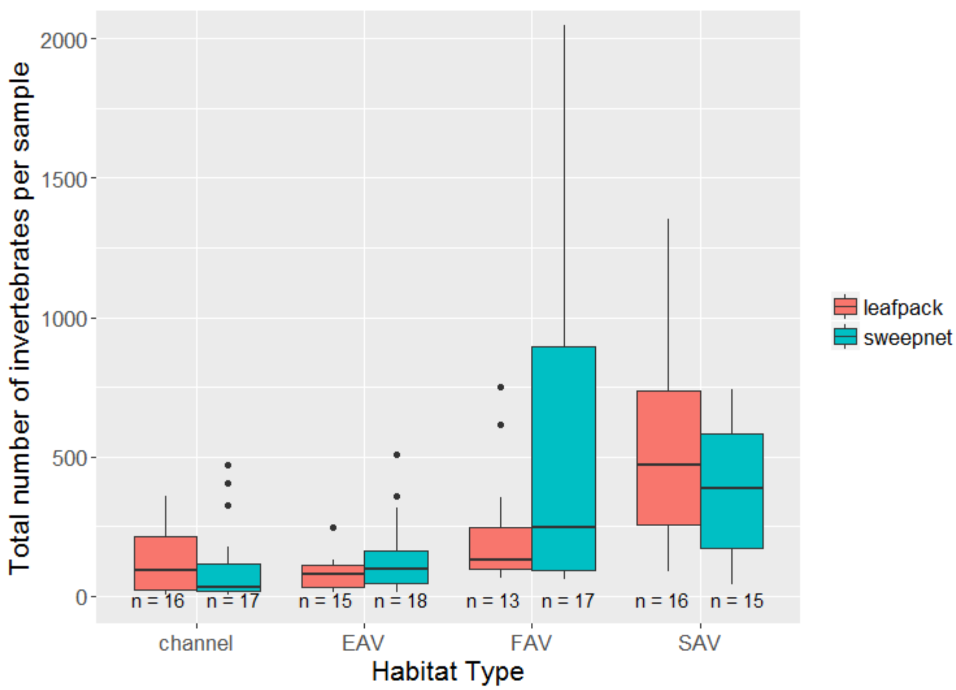


Figure I.9. Distribution of total catch of leaf packs and sweep nets in each habitat type. Models support significantly higher catch in FAV and SAV than in EAV and channel habitats.

When ranking all possible models of species richness, the highest ranked model (delta AICc > 2) included only sample type and habitat type (Table I.8). There was much less support for models including region, month, or interactions between sample type and target. In particular, sweep nets had higher species richness than leaf packs, and SAV and FAV samples had higher richness than channel or EAV samples (Figure I.10). Species-accumulation curves developed with the two methods demonstrate that sweep nets will characterize the community faster and more thoroughly (Figure I.11). Leaf packs predicted a lower total species richness than sweep nets (23 versus 24 species), and leaf packs required 6 samples, whereas sweep nets only required 4 samples to capture 80% of the total predicted species.

Table I.8. Coefficients for top ranked model predicting total invertebrate catch of sweep nets and leaf packs. Only sample type and habitat type were included in the top model; region and month were not supported. Top model: Richness ~ Habitat + sample type, Residual standard error: 5.429 on 41 degrees of freedom, Multiple R-squared: 0.2915, Adjusted R-squared: 0.2224, F-statistic: 4.217 on 4 and 41 DF, p > F: 0.005968

Factor	Estimate	St. Error	t value	p value
Intercept	12.808	1.76	7.725	<0.001**
Habitat: EAV	3.083	2.216	1.391	0.172
Habitat: FAV	6.073	2.267	2.679	0.011*
Habitat: SAV	4.593	2.267	2.026	0.049*
Sample type: Sweep Net	4.718	1.604	2.941	0.005**

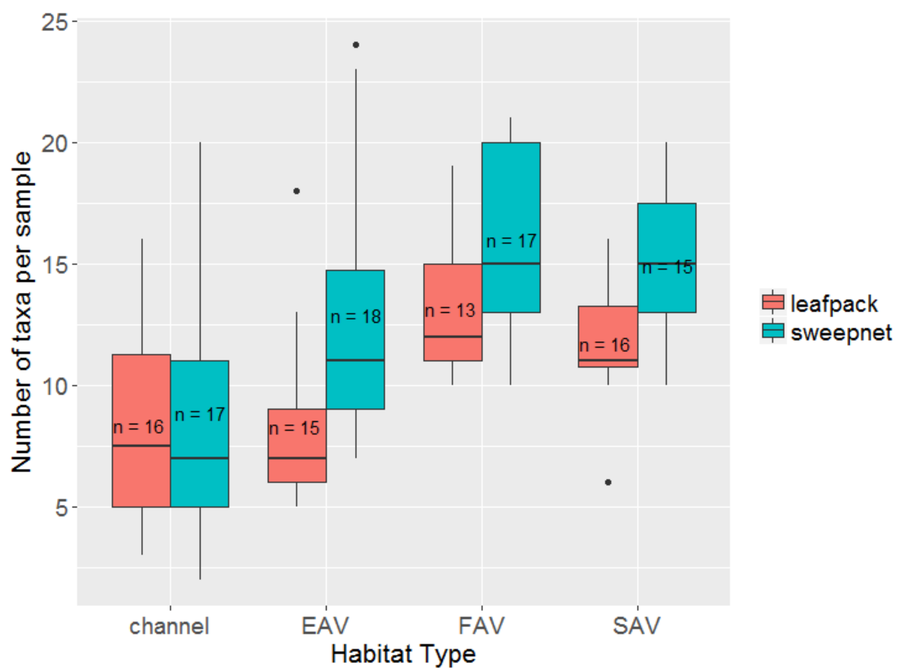


Figure I.10: Distribution of species richness for sweep nets and leaf packs in various sample types. Models support significantly higher richness for samples collected with sweep nets, and significantly higher richness for FAV and SAV samples than EAV or channel samples.

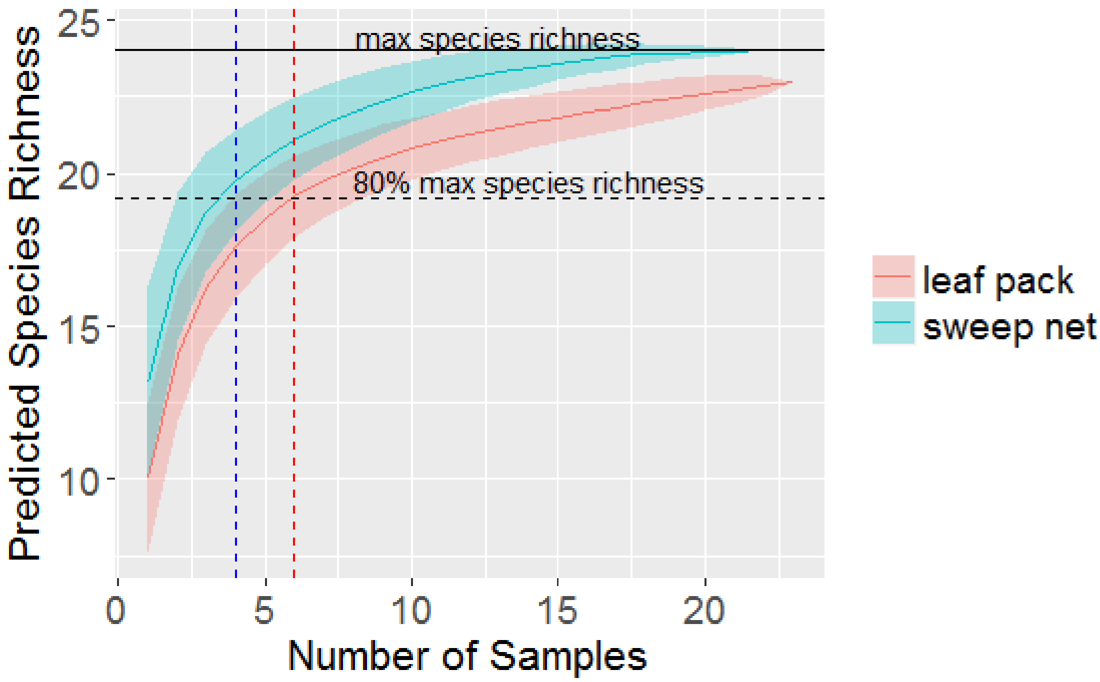


Figure I.11. Species-accumulation curves for leaf packs and sweep nets. Leaf packs predicted lower total species richness than sweep nets, and leaf packs require more samples for the same percentage of total species.

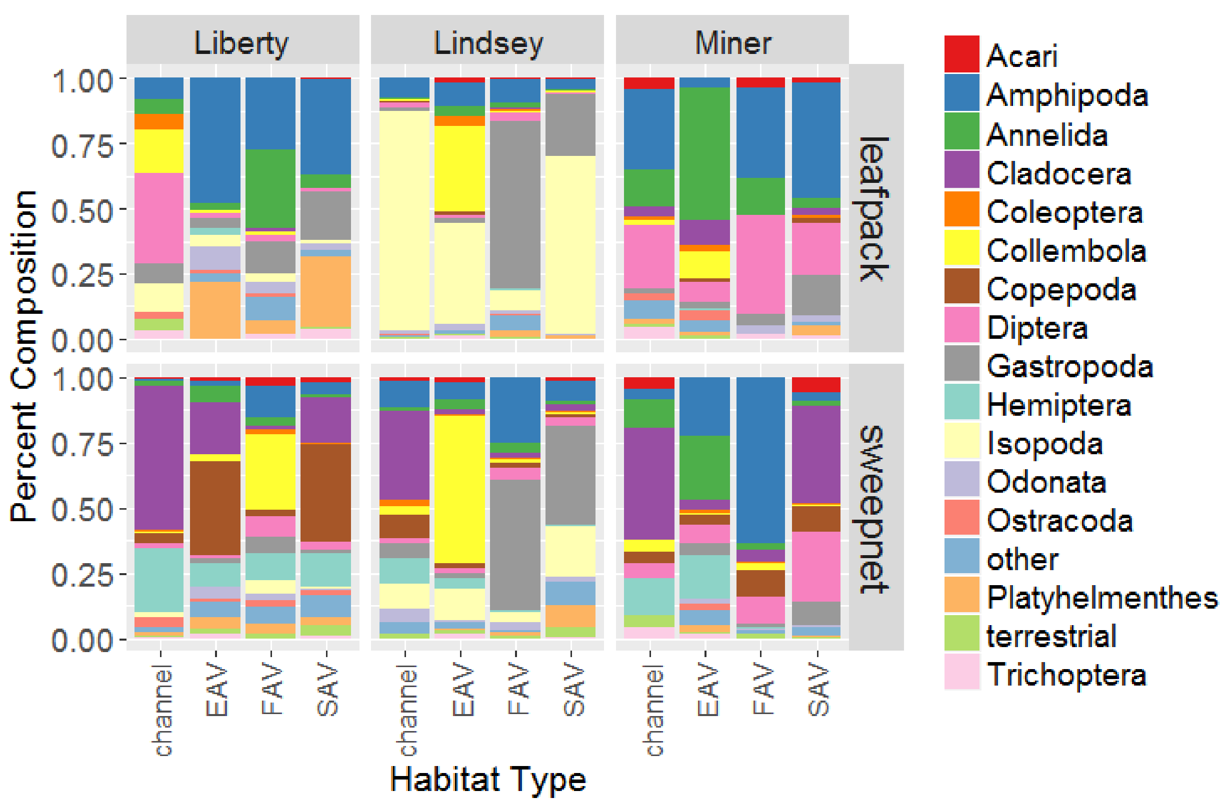


Figure I.12. Relative percent composition of major taxa in samples collected with leaf packs and sweep nets in various habitats in the three different regions (Liberty, Lindsey, and Miner). Taxa that made up less than 0.5% of the total catch were combined into the "other" category to simplify the graph. PERMANOVA showed significant differences between habitat types, between regions, and between sample types (Table I.9).

Community composition also varied between habitat types and between regions. An overall PERMANOVA results showed that there were significant differences between habitat type, sampler type, and region, but not between months. However, comparisons of PERMANOVA results for explanatory variables within a given sampler type indicate that sweep net samples have significant differences between region and habitat type, whereas leaf pack samples only showed differences between regions and did not show differences between habitat types (Table I.9, figure I.12). This can be seen in the NMDS plots, where hulls surrounding habitat types in leaf pack samples have a much higher degree of overlap than hulls surrounding regions (Figure I.13A), and the consistent dominance of particular taxonomic groups among habitat types for each region (Figure I.12). Sweep net NMDS plots had relatively less overlap between hulls for habitat types (Figure I.13B), though habitat explained less of the variation than region (R^2 = 0.16 versus R^2 = 0.30, Table I.9).

Table I.9. Results of PERMANOVA performed on the entire data set and on subsets of the dataset using sweep nets only or leaf packs only.

A) Overall PERMANOVA

Factor	DF	Sum of Sqs	Mean Sqs	F value	R^2	p value
Habitat type	3	1.98	0.66	3.29	0.153	0.001**
Sample type	1	1.24	1.24	6.15	0.096	0.001**
Region	2	1.83	0.91	4.54	0.141	0.001**
Residuals	39	7.84	0.20		0.608	

B) Leaf packs only

Factor	DF	Sum of Sqs	Mean Sqs	F value	R^2	p value
Habitat Type	3	0.904	0.301	1.533	0.157	0.107
Region	2	1.503	0.752	3.825	0.261	0.001**
Residuals	17	3.341	0.196		0.581	

C) Sweep nets only

Factor	DF	Sum of Sqs	Mean Sqs	F value	R^2	p value
Habitat Type	2	0.9532	0.477	2.554	0.161	0.011*
Region	3	1.801	0.600	3.217	0.303	0.003*
Residuals	17	3.172	0.187		0.535	

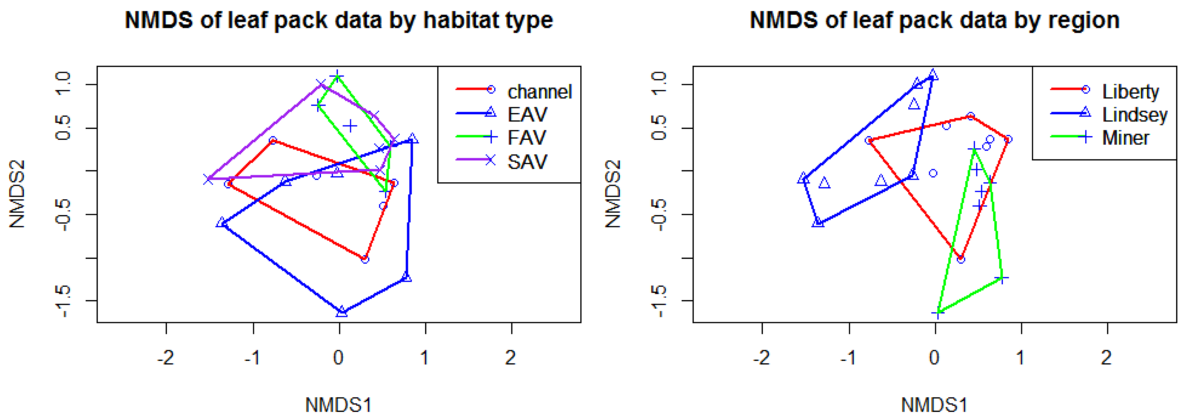


Figure I.13 A). Non-metric multidimentional scaling plots for all leaf pack data showing grouping by habitat types and by regions (replicates summed within sampling sites to avoid pseudoreplication). Stress = 0.159. As can be seen by degree of overlap between hulls, community composition between habitat types was not significantly different (PERMANOVA results: F-statistic = 1.56, p = 0.115, R^2 = 0.153), whereas community composition between regions was significantly different (PERMANOVA results: F-statistic = 3.125, p = 0.004, R^2 = 0.280)

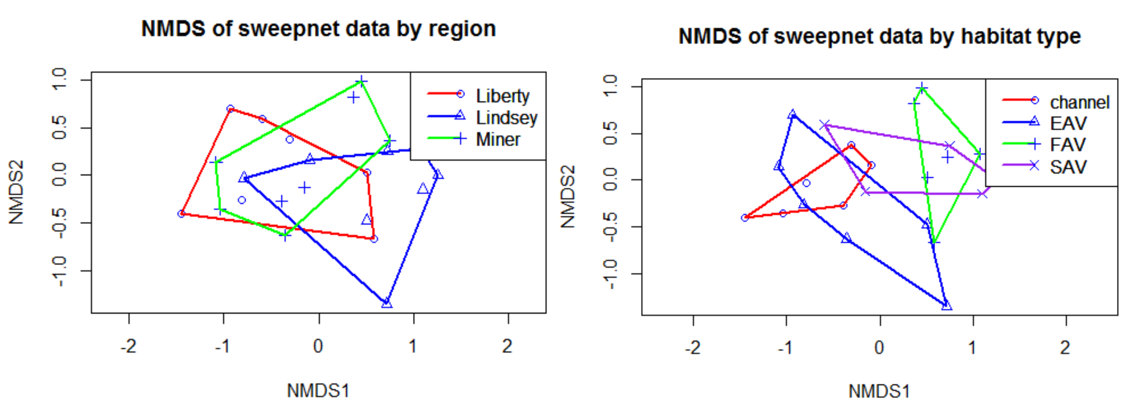


Figure I.13 B). Non-metric multidimentional scaling plots for all sweep net data showing grouping by habitat types and by regions (replicates summed within sampling sites to avoid pseudoreplication). Stress = 0.159. There were significant differences both between regions (PERMANOVA F-statistic = 3.532, p = 0.002, R^2 = 0.211), and between habitat types (PERMANOVA F-statistic = 4.47, p = 0.001, R^2 = 0.292)

SIMPER analysis highlights which taxa drove the observed difference in overall community composition between regions and habitat types (Table I.10). In particular, high abundances of isopods and snails in Lindsey Slough, and the high abundance of amphipods and Diptera in Miner Slough drove much of the differences between the regions. The high abundances of snails in FAV and SAV, the high abundance of collembolans in EAV, and high abundance of copepods in channel habitat drove the observed differences between habitat types.

Table I.10. Contribution of each taxon to observed dissimilarity between regions and habitat types for leaf pack and sweep net data from a Similarity Percentages analysis (SIMPER).

	Taxonomic group						
Region	Snails	Amphipoda	Isopoda	Cladocera	Diptera	Collembola	Copepoda
Lindsey v Liberty	0.192	0.162	0.1562	0.0905	0.062	0.0991	0.0841
Lindsey v Miner	0.1824	0.1887	0.1551	0.1136	0.1028	0.0785	0.0393
Liberty v Miner	0.0889	0.2261	0.0284	0.1423	0.1364	0.041	0.1
Habitat type							
channel v FAV	0.1928	0.2117	0.0947	0.1439	0.1034	0.0458	0.0455
channel v SAV	0.1943	0.1743	0.1364	0.1445	0.1066	0.0179	0.0696
channel v EAV	0.0271	0.1457	0.127	0.1695	0.114	0.1125	0.0881
FAV v SAV	0.2546	0.2557	0.107	0.0341	0.0868	0.0457	0.0633
FAV v EAV	0.1833	0.2182	0.0752	0.0897	0.072	0.1162	0.0695
SAV v EAV	0.1876	0.1775	0.1168	0.0946	0.0688	0.1036	0.0893

Ponar grab versus benthic core versus benthic trawl comparison

All forms of benthic sampling had some logistical difficulties. The PVC corer was inexpensive and simple, but it could only be used when the water was less than 1m deep, and often required multiple attempts to extract a sample. Extracting a sample was particularly difficult in very hard or very soft substrates. The ponar grab also had difficulties in extremely hard or extremely soft substrates, and often required multiple attempts to deploy correctly. The ponar is heavy (>20kg empty) and required a davit and winch to deploy from a boat. The benthic trawl was prone to snagging on obstructions or vegetation along the bottom of the channel. The trawl could be used on hard substrates where the ponar could not be used, but filled with mud in very soft substrates.

The ponar grab and PVC core both had a low coefficient of variation (0.65 and 0.67 respectively), which was similar to EMP's ponar grab coefficient of variation (0.81). The benthic trawl had a somewhat higher coefficient of variation (1.35).

Total CPUE for the ponar grab, PVC core, and EMP ponar grabs were not normally distributed, and did not have homogeneous variance. Therefore, we used a Kruskal-Wallace test and found significant differences between total catch for all three sample types (H value = 9.55, p = 0.008), with PVC cores having the highest total catch per unit area, followed by the EMP ponar, with lowest catch in our ponar samples (Figure I.14). The benthic sled had a significantly higher proportion of catch found in fish diets than the ponar grab or PVC core (Figure I.8A, binomial GLM z value = 3.15, p = 0.002).

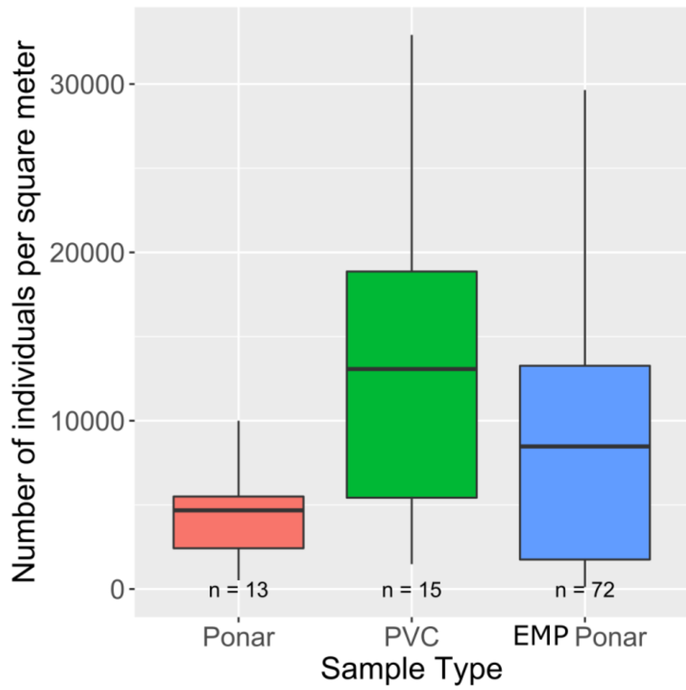


Figure I.14. CPUE for FRP ponar grabs, PVC cores, and EMP's ponar grabs. Average catch was significantly different between all three sample types.

Species richness and community composition were also different between sampler types. The data were best described using a Poisson distribution, and a GLM with a log link function found that PVC cores had marginally lower species richness and benthic trawls had significantly higher species richness than EMP's ponar or our ponar grab (Figure I.15, Table I.11). The species comprising each sample also differed between sampler types (Figure I.16). The NMDS plot shows a high degree of overlap between the community composition of the PVC core, our ponar grab and the EMP ponar grab (Figure I.17). The larger hull around our ponar grab results may be due to quantifying zooplankton and other invertebrates not included in EMP's analysis. The hull around the benthic trawl is completely separate, demonstrating greater separation in community composition. PERMANOVA found all four sample types to be significantly different from each other (F-statistic = 9.5603, R^2 = 0.20387, $p < 0.001$). SIMPER analysis showed that the observed differences were primarily due to low proportions of Annelida in the benthic trawl, high proportions of Annelida in the PVC core, high proportions of Bivalvia in the ponar grabs, high proportion of Diptera in our ponar grab, and large numbers of Collembolla in the PVC core (Table I.12).

Table I.11. Coefficients for generalized linear model of species richness versus sampler type using a Poisson distribution. Null deviance: 140.97 on 115 degrees of freedom Residual deviance: 105.45 on 112 degrees of freedom.

Factor	Estimate	Std. Error	z value	p value
Intercept (Ponar)	1.853	0.110	16.890	<0.001**
PVC	-0.285	0.161	-1.771	0.077 .
Benthic Trawl	0.479	0.134	3.563	<0.001**
EMP Ponar	0.035	0.119	0.293	0.769

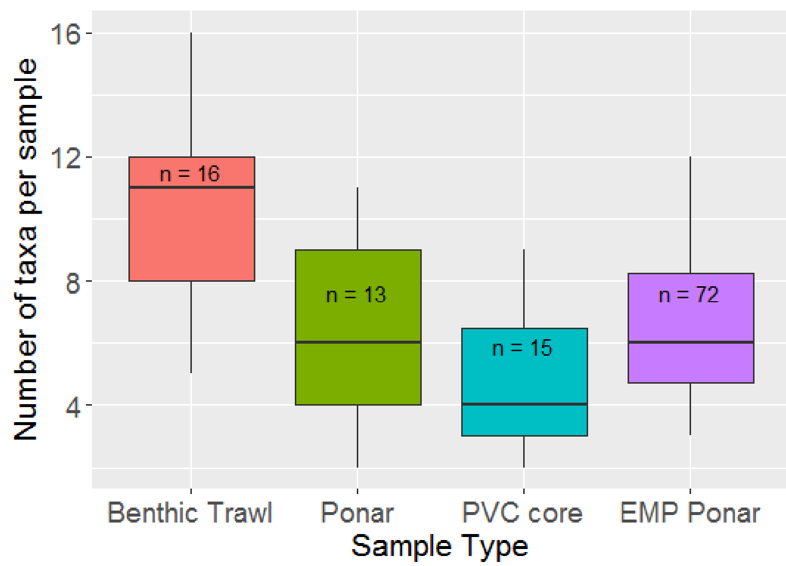


Figure I.15. Number of taxa collected per sample for the different sampling types. Models show no difference in species richness between our ponar grab and the EMP ponar grab, however our PVC core had marginally lower richness and our benthic trawl had significantly higher richness than the ponar grabs.

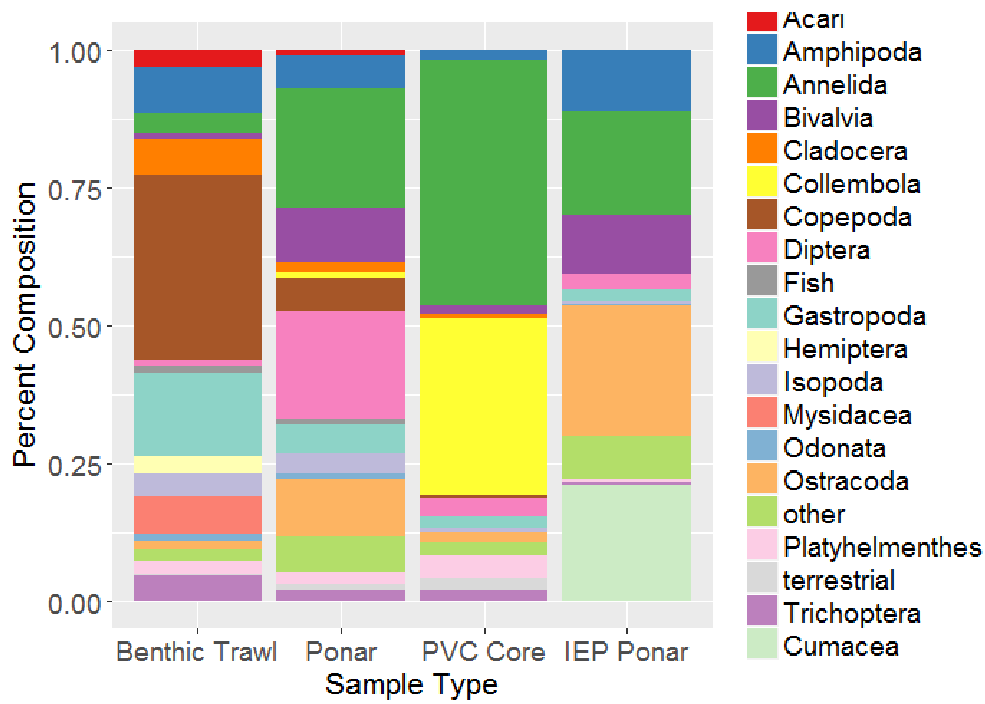


Figure I.16. Relative percent composition of major taxa in samples collected with ponar grabs, benthic trawls, and PVC cores. Taxa that made up less than 0.5% of the total catch were combined into the "other" category to simplify the graph. PERMANOVA showed significant differences between the three sampler types ($F = 9.5603$, $R^2 = 0.20387$, $p < 0.001$).

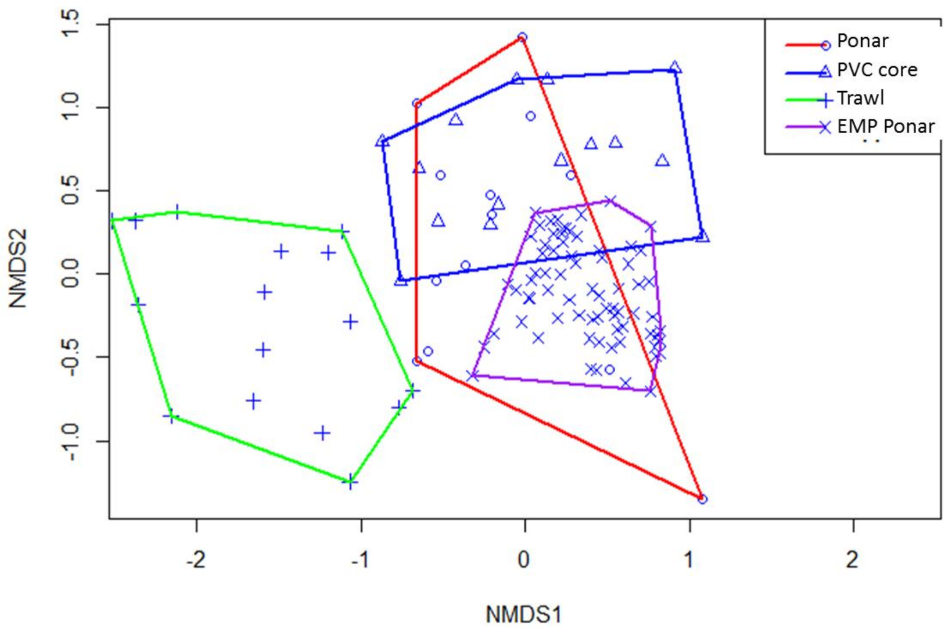


Figure I.17. Non-metric multidimentional scaling plots for benthic samples with hulls grouping by sampler types. Stress = 0.18. As can be seen by lack of overlap between hulls, community composition was significantly different between sampler types.

Table I.12. Contribution of most influential taxa to observed dissimilarity between benthic sampling methods from a Similarity Percentages analysis (SIMPER).

	Annelida	Diptera	Bivalvia	Amphipoda	Collembola
Sled v. Ponar	0.272	0.255	0.171	0.1389	0.001
Sled v. PVC	0.604	0.134	0.034	0.074	0.101
Sled v. EMP Ponar	0.572	0.01	0.167	0.1655	0
Ponar v. PVC	0.551	0.131	0.0495	0.0678	0.103
Ponar v. EMP Ponar	0.513	0.141	0.0955	0.115	0.001
PVC v. EMP Ponar	0.579	0.095	0.053	0.079	0.106

Oblique versus benthic versus neuston

We successfully collected 35 neuston trawls, 16 benthic trawls, and 25 oblique trawls. Logistically, neuston trawls were easiest since the net itself is light and deployed off the side of the boat using a simple pole. They could also be deployed by hand and walked along the bank in small channels inaccessible by boat, and were less subject to clogging with vegetation and detritus. Benthic trawls required a heavy sled, and were most susceptible to clogging with sediment and snagging on debris on the channel bottom. Oblique trawls were less subject to snagging; however, in order to be towed correctly, the tow rope had to be shortened while under tension. This is difficult to accomplish by hand, and may require a hydraulic winch in many situations. Oblique trawls require at least 1 meter of water depth to be towed and 2.5 meters of depth to sample different portions of the water column equally.

The oblique trawls had a slightly lower coefficient of variation in CPUE than the benthic trawls and neuston trawls (neuston CV = 1.42, oblique CV=1.01, benthic CV=1.35). Log-transformed catch data met the assumptions for linear models, and a generalized linear model on the log-transformed CPUE found that oblique trawls had a slightly higher CPUE than benthic trawls (Figure I.19, $F_{1,39} = 9.77$, $p = 0.003$, $R^2 = 0.18$). A binomial model on the catch of invertebrates included in fish diets between the three sampler types found that oblique trawls had the highest percentage of fish food critters, followed by neuston trawls, and finally benthic trawls (Table I.13, Figure I.8A).

Table I.13. Results of a binomial model on percentage of catch made up of fish food invertebrates for the different trawling methods.

Factor	Estimate	Std. Error	z value	p value
Intercept (Oblique Trawl)	-0.099	0.008	-12.967	<0.001**
Benthic Trawl	-0.132	0.012	-10.791	<0.001**
Neuston Trawl	0.054	0.011	4.958	<0.001**

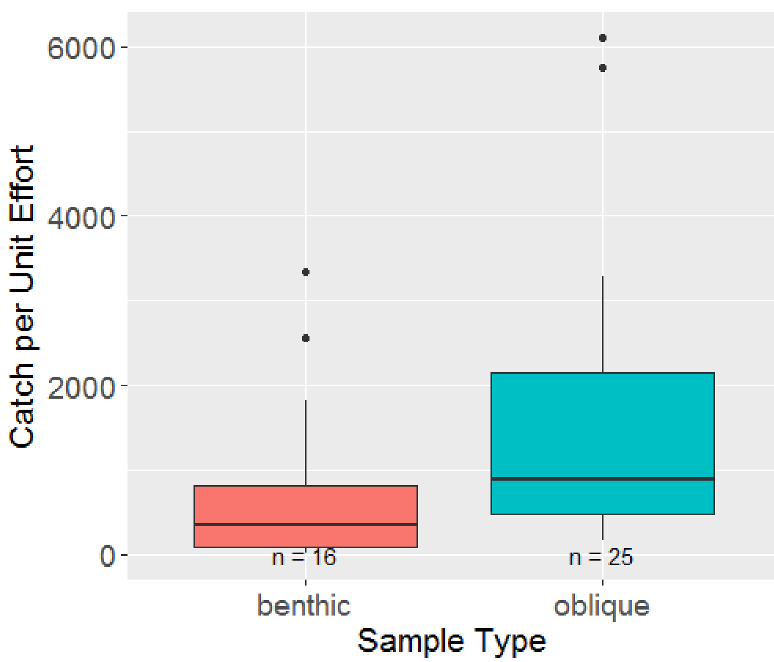


Figure I.19. Distribution of CPUE for benthic and oblique trawls. Oblique trawls had a significantly higher CPUE.

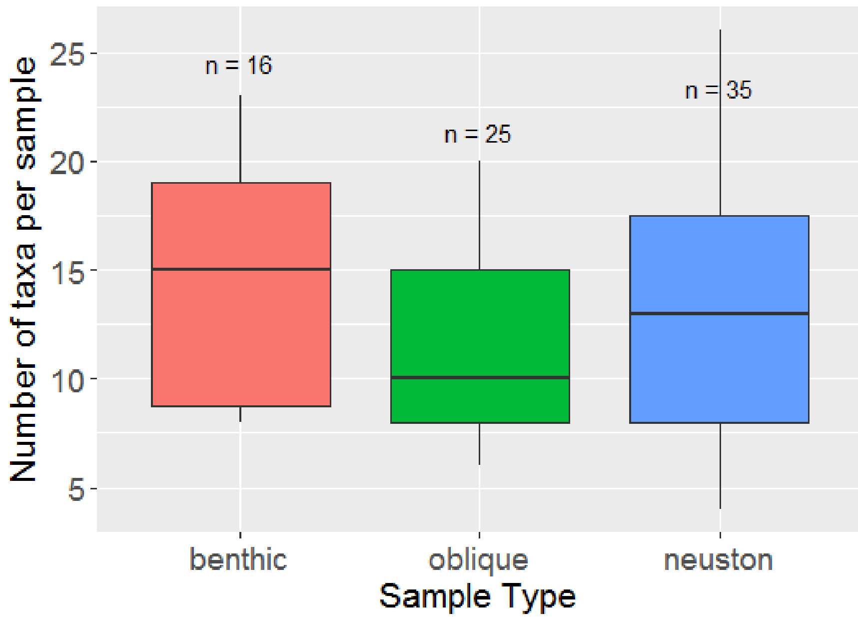


Figure I.20. Distribution of species richness for each sample collected by different trawling methods.

Species richness data met the assumptions for linear models, and a GLM of richness versus sampler type found no significant differences in species richness (Figure I.20, t = 1.43, 1.938, p = 0.16, 0.06). However, there were differences in the identity of those species (Figure I.21). The NMDS plot shows some overlap between sampler types (Figure I.22), however each sampler type also covers some area not covered by the other two sample types. PERMANOVA results reveal significant differences between all three sample types (F-statistic = 13.21, $p < 0.001$), though sample type explained only about a quarter of the variation ($R^2 = 0.266$). The SIMPER analysis showed that the observed differences in community composition were driven chiefly by the higher proportion of Cladocera in the oblique and neuston trawls, higher proportion of Copepoda in the oblique trawl, and the higher proportion of Amphipoda in the benthic trawl (Table I.14).

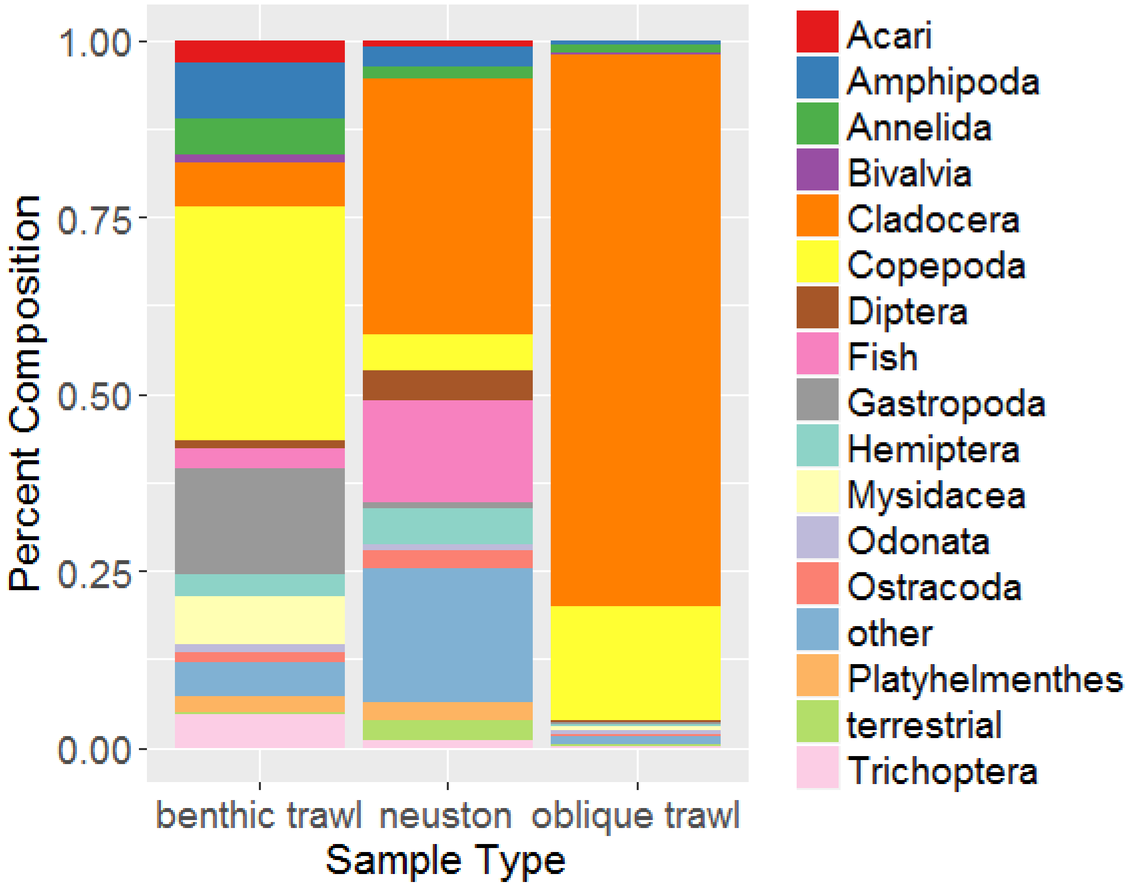


Figure I.21. Relative percent composition of major taxa in samples collected with benthic, oblique, and neuston trawls. PERMANOVA showed significant differences between the three sampler types (F-statistic = 13.21, $p < 0.001$, $R^2 = 0.266$). Taxa that made up less than 0.5% of the total catch were combined into the “other” category.

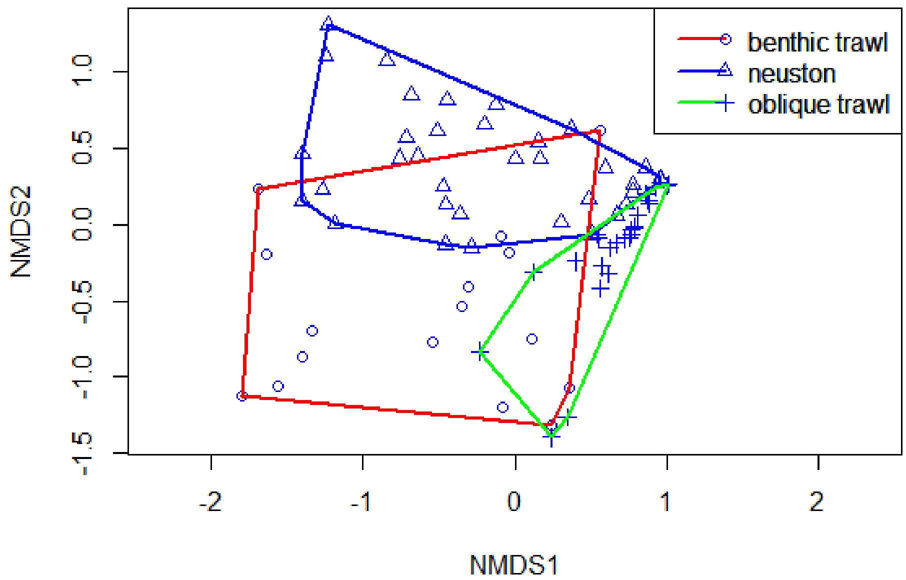


Figure I.22. Non-metric multidimentional scaling plots for open water samples with hulls grouping by sampler types. Stress = 0.153. As can be seen by regions of non-overlapping hulls, community composition was significantly different between sampler types.

Table I.14. Contribution of each taxon to observed dissimilarity between benthic sampling methods from a Similarity Percentages analysis (SIMPER).

	Taxonomic group					
Sampler type	Cladocera	Copepoda	Amphipoda	Annelida	Diptera	Terrestrial
Benthic v. Oblique	0.269	0.199	0.138	0.057	0.04	0.008
Benthic v. Neuston	0.204	0.152	0.129	0.052	0.089	0.067
Oblique v. Neuston	0.352	0.533	0.028	0.028	0.119	0.087

The mean CPUE of amphipods and mysids in our benthic trawls was higher than the IEP FMWT or EMP's mysid trawl, though there was extremely high variation in catch amongst sites and throughout the year (Figure I.23). Zero-inflated Poisson models of CPUE found both the probability of catching amphipods was significantly higher for the FRP benthic and oblique trawls. The size of catch of was significantly different between all four sampler types. For mysids, probability of catch was the same between sampler types, though size of catch was significantly different between all sampler types (Table I.15). The DWR Yolo Bypass drift net caught a similar community composition to our neuston trawl (Figure I.24). They caught a somewhat higher proportion of Diptera, Hemiptera and Annelida, with fewer Collembola.

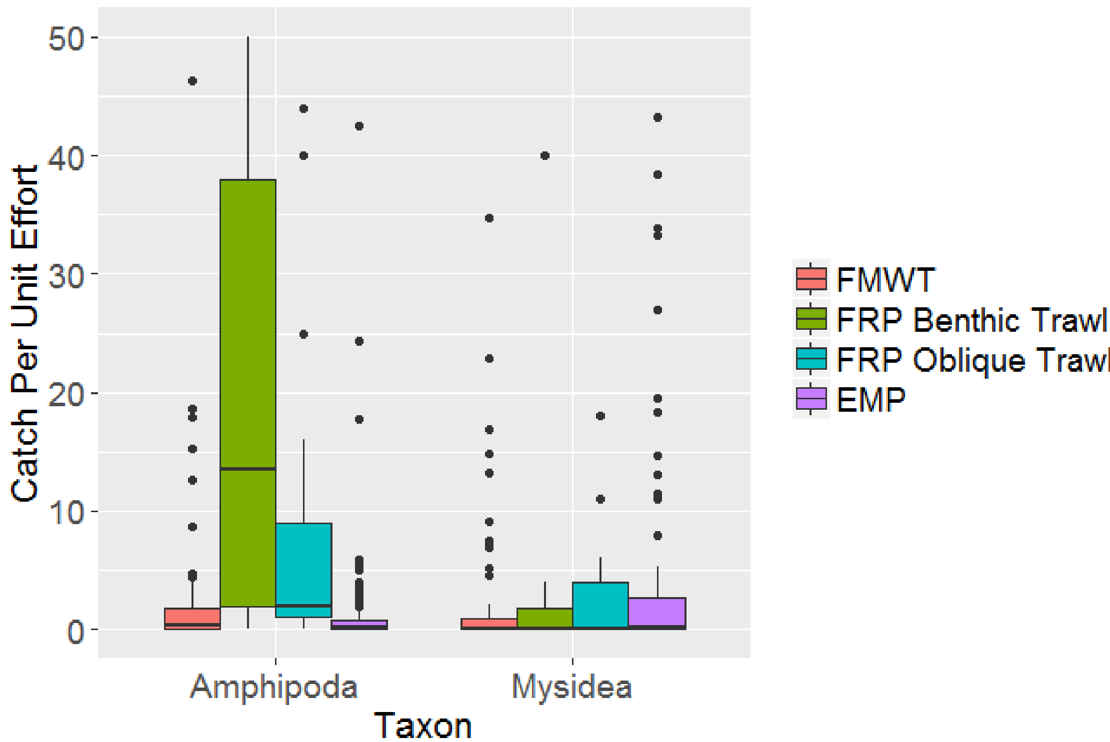


Figure I.23. CPUE of Amphipoda and Mysidea caught by the EMP's Zooplankton Study mysid net (in purple), the Fall Midwater Trawl's mysid net (in red) and our benthic trawls (green) and oblique trawls (blue). Note that 11 outliers are too high to plot on this graph.

Table I.15. Results of a zero-inflated Poisson model on catch of mysids and amphipods in FRP trawls and IEP long-term monitoring surveys. The count model is a Poisson model of CPUE rounded to the nearest whole individual with a log link, and the zero-inflated model is a binomial model with a logit link.

Mysids				
Count Model	Estimate	Std. Error	z value	p value
Intercept (FMWT)	3.011	0.046	65.065	<0.001***
EMP	-0.394	0.066	-5.966	<0.001***
FRP Benthic	0.929	0.078	11.959	<0.001***
FRP Oblique	-1.019	0.132	-7.733	<0.001***
Zero-inflated model	Estimate	Std. Error	z value	p value
Intercept (FMWT)	0.908	0.247	3.674	<0.001***
EMP	-0.512	0.334	-1.532	0.125
FRP Benthic	-0.119	0.593	-0.201	0.841
FRP Oblique	-0.333	0.485	-0.688	0.492

Amphipods				
Count Model	Estimate	Std. Error	z	p value
Intercept (FMWT)	1.637	0.075	21.692	<0.001***
EMP	3.290	0.079	41.733	<0.001***

FRP Benthic	0.576	0.104	5.510	<0.001***
FRP Oblique	-0.674	0.106	-6.353	<0.001***

Zero inflated model	Estimate	Std. Error	z	p value
Intercept (FMWT)	0.071	0.236	0.301	0.763
EMP	-2.017	0.792	-2.547	0.011*
FRP Benthic	-1.730	0.595	-2.910	0.004**
FRP Oblique	0.493	0.277	1.784	0.074 .

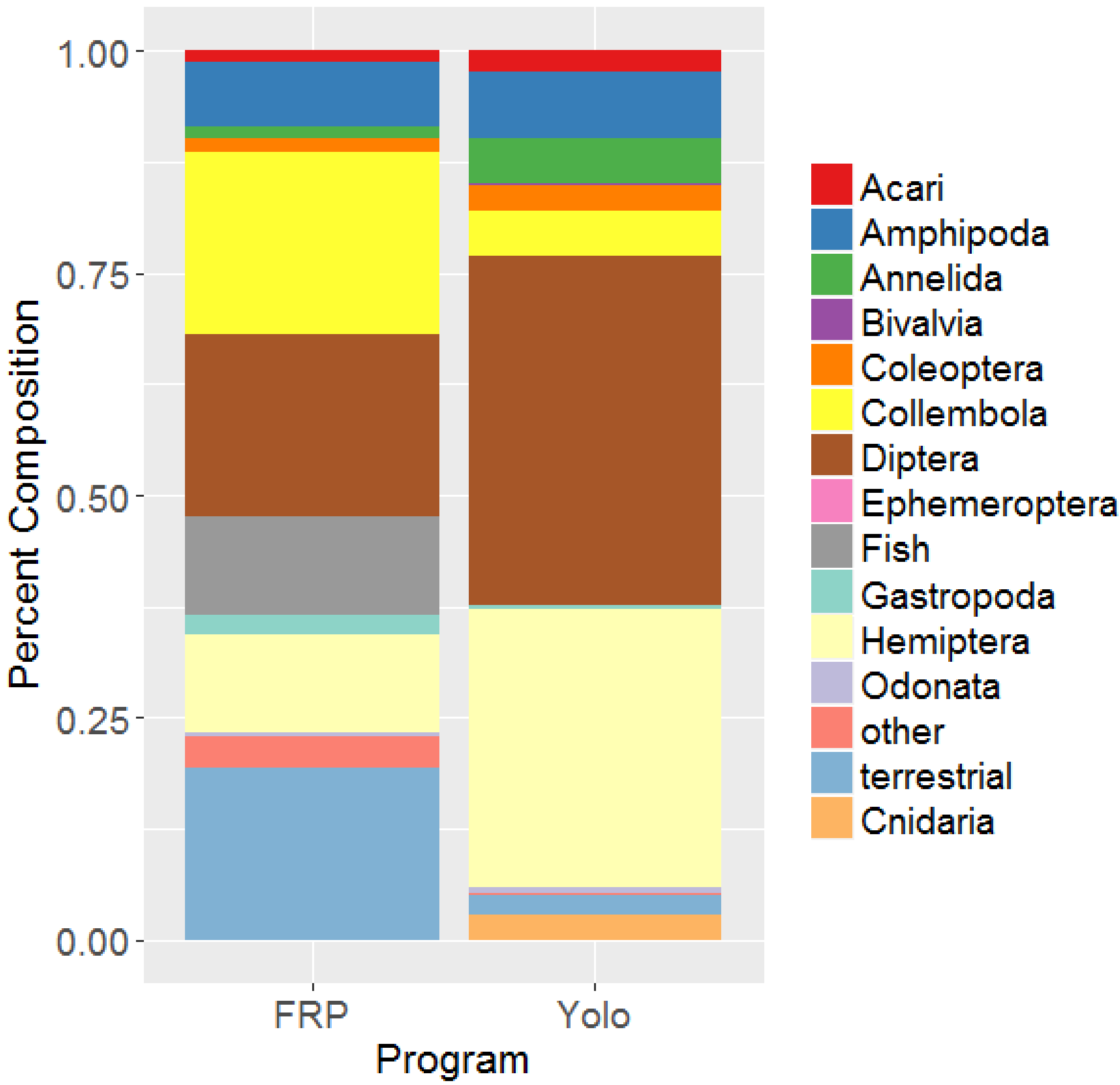


Figure I.24. Percent composition of total catch from FRP neuston tows and DWR Yolo Bypass drift nets. Note that zooplankton were not enumerated in Yolo Bypass drift nets, so Copepoda and Cladocera have been removed from our data. Taxa that made up less than 0.5% of the total catch were combined into the “other” category.

Incidental fish catch

We want to choose macroinvertebrate gear types with low incidental take of fish, and there were significant differences in average catch of fish per sample (Kruskal-Wallace H value = 100.13, $p < 0.001$, Figure I.25). On a catch-per-sample basis, the highest take of fish was from the oblique trawls, followed by neuston and benthic trawls, and sweep nets. Ponars and PVC cores caught a single individual each, and no fish were caught in leaf packs (Figure I.25). Overall, Prickly Sculpin were caught most often, followed by Mississippi Silversides and Tridentiger gobies, none of which is considered threatened or endangered (Figure I.26). The only fish we collected considered a Species of Special Concern was the Sacramento Splittail (41 individuals total), which were caught most frequently in the neuston trawl (25 individuals in 35 trawls; Figure I.26).

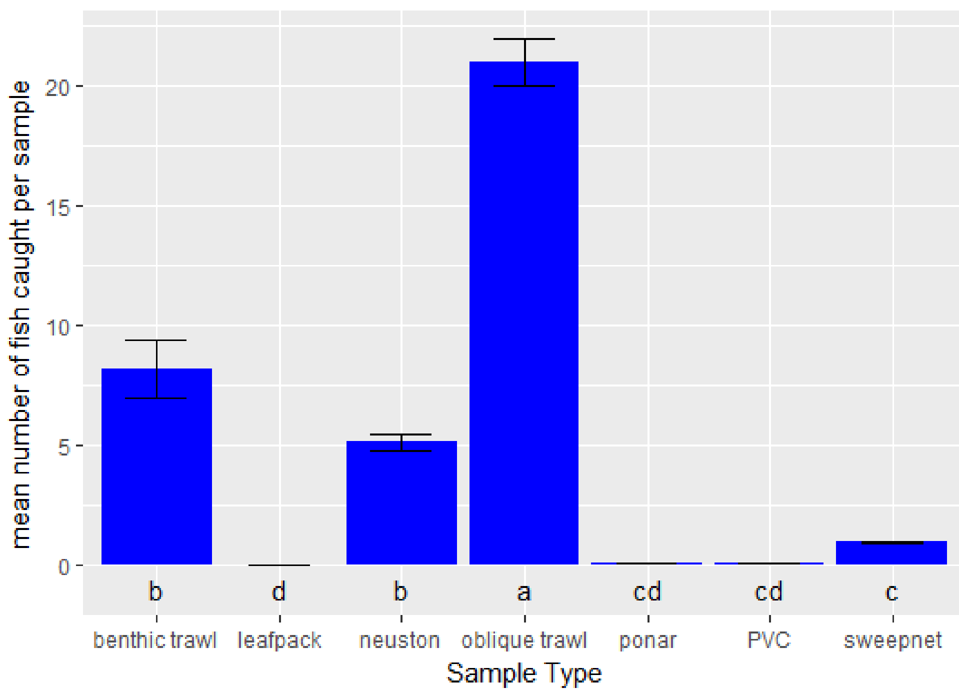


Figure I.25. Mean number of fish caught per sample for each sampler type +/- 1 standard error. Letters represent groups with no significant difference as calculated by a Kruskal-Wallace test (H value = 100.13, p <0.001).

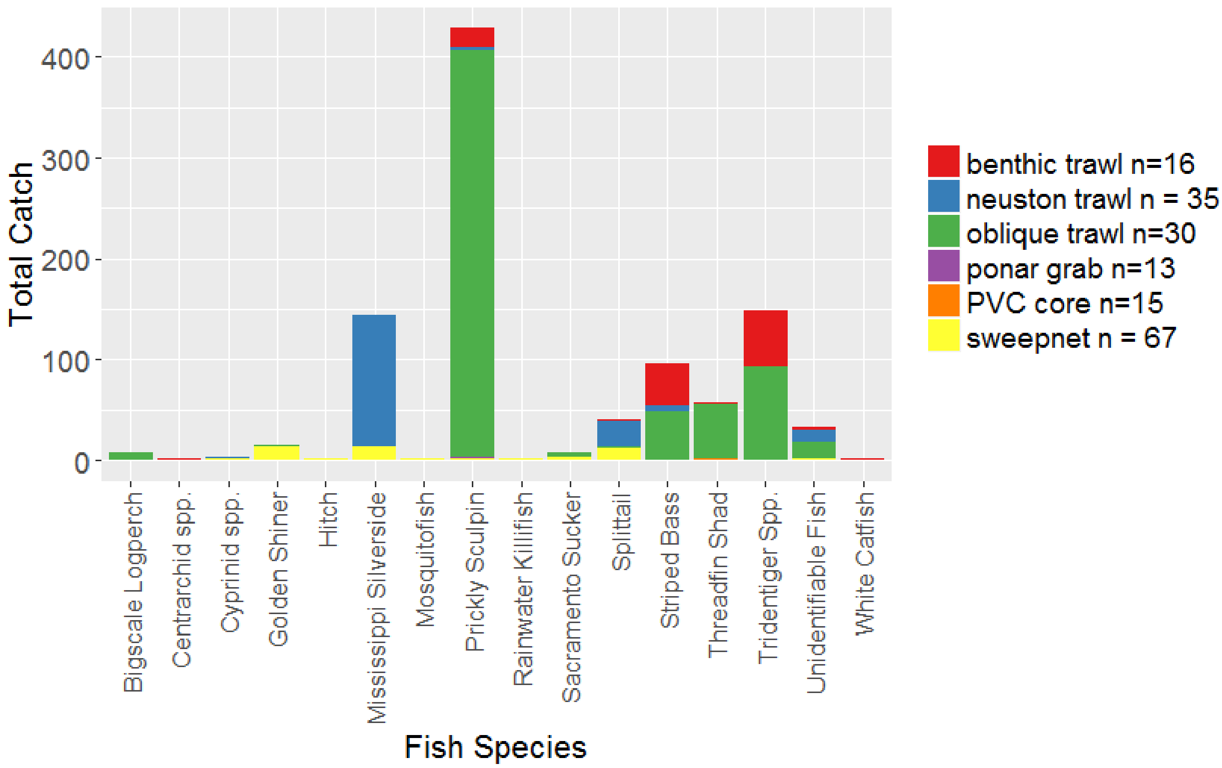


Figure I.26. Total catch of fishes during invertebrate sampling. Bar color represents sample type.

Discussion:

During Phase II, we were able to increase the spatial extent and replication of the Phase I pilot sampling program, allowing us to definitively choose sampling methods for macroinvertebrates in long-term monitoring of wetlands. In vegetated and littoral habitat we will use sweep nets instead of leaf packs for regular sampling. We will use small PVC cores in shallow water and ponar grabs in deeper water. Both methods can easily be compared to regular EMP benthic monitoring ponar grabs. While we made progress in learning which techniques work in channel habitat, we will still investigate whether to recommend benthic trawls, oblique trawls, or both in combination with neuston trawls for long-term monitoring. We will investigate different trawling methods and increase our comparisons with IEP surveys in the 2017 Phase III sampling. Our analysis of leaf packs and sweep net data also helped increase our understanding of macroinvertebrate community diversity across regions and habitat types, which help support broader hypotheses identified in the Tidal Wetlands PWT Monitoring Framework.

Choosing sampling methods

When sampling for macroinvertebrates in shallow, vegetated habitat where we cannot trawl, the FRP monitoring program will use sweep nets. Sweep nets had higher variability than leaf packs, they were more cost effective, were less subject to loss or vandalism, were better able to distinguish between habitat types, and had higher species richness, thus giving a more accurate picture of invertebrate community composition with less effort. This is in keeping with research from other areas that found active methods, such as sweep nets, gave a more accurate view of community composition than substrate colonization traps (Turner and Trexler 1997; Blocksom and Flotemersch 2005). Sweep nets have also been found to better differentiate between habitat types within a wetland than other sampler types (Robinson et al. 2011). More time-intensive active sampling methods, such as throw-traps, may have even higher species richness (Meyer et al. 2011), but the increase in sampling time makes them less cost-effective, and the Phase I pilot study found them difficult to deploy consistently in the Delta.

We found that four sweep net samples include 80% of the taxa present on a site, versus six leaf packs, meaning the ratio of staff time per species for leaf packs versus sweep nets is higher than the ratio of staff time per sample (Figure I.10.5). An effort of four samples per site is similar to results of other studies of effort required for characterizing macroinvertebrate diversity (Halse et al. 2002). Sweep nets also better characterized invertebrates found in fish diets (Figure I.8A), which is the goal of our sampling program. However, the high variation in total catch may mean more samples will be necessary to describe differences in invertebrate density and biomass than to describe differences in diversity (as suggested by Simenstad et al. 2000). Sweep nets were also more likely to capture fish, though this averaged less than one fish per sample (Figure I.25), and no at-risk fish species were caught in sweep nets in 2016 (Figure I.26).

There may be some situations where sweep nets are too highly variable to allow differentiation between regions, in which case, leaf packs may be deployed since they have been used effectively to evaluate wetland restoration in other areas (Scatolini and Zedler, 1996), and passive samplers may be sensitive to different stressors than active methods (Blocksom and Flotemersch. 2005). However, they should only be used in emergent vegetation where they most accurately replicate the surrounding habitat and are least likely to be lost.

When sampling benthic infauna, we will use both ponar grabs and PVC cores, depending on water depth. Both methods were effective at collecting similar diversity of benthic organisms, and differences in community composition were likely due to different habitat types rather than sampler types. The PVC cores analyzed in this study all came from vegetated marsh plains, whereas ponar grabs all came from deep (> 2m) channel bottom habitat. Other studies of wetland macroinvertebrates found that channel order, vegetated area, and substrate type all affect community composition of benthic core samples (Robinson et al. 2011, Howe et al. 2014). Trawls were better at characterizing epibenthic fish food (particularly *Americorophium* in the order Amphipoda) given their higher proportion of catch found in fish diets (Figure I.8A), but the benthic infauna found in the cores is important in characterizing benthic grazing rates and processes. Benthic trawls also capture more fish than the other two benthic sampling types (Figure I.25), so if characterizing the larval fish community is not a priority, this may be seen as detrimental to the fish community.

While benthic trawls and ponar grabs sample different aspects of the community, our program does not have the resources to collect ponar grabs, benthic trawls, oblique trawls, and surface trawls (currently being evaluated for larval fish catch) at all sites. In Phase III, we will continue to evaluate the different trawling methods (see below) to determine what combination of sampling techniques gives an adequate picture of both the benthic and the pelagic invertebrate community.

When sampling channel habitat, the benthic, oblique, and neuston trawls all captured significantly different components of the community. Benthic trawls captured a lower proportion of invertebrates commonly found in fish diets (Figure I.8A). However, the benthic trawls caught higher numbers of amphipods and mysids, which are larger and of greater nutritional value than the Copepoda and Cladocera that dominated fish food catch in the oblique trawls (Figure I.21; Tiffan et al. 2014). Furthermore, the three types of trawls were not always paired samples, so differences between locations, dates, and habitat types may have confounded our results. Because we had relatively small sample size, we could not use these factors as covariables in our analyses.

The oblique trawl should provide a depth-integrated sample of the invertebrates in the water column, capturing epibenthic, pelagic and surface invertebrates, but our oblique trawls were dominated by pelagic zooplankton, with very few epibenthic or surface invertebrates. This may have been due to differences in locations, or logistical difficulties in pulling the trawl. Because many zooplankton migrate vertically on tidal and diurnal cycles, relative abundance and vertical position of important food resources may change over the course of the day (Kimmerer et al. 2002; 2014), making oblique trawl results difficult to interpret. In very shallow channels, vertical position of both the zooplankton and the sampling gear may not be important, since fish can forage throughout the water column. Increases in sample size, and systematic paired benthic and oblique trawls in our Phase III pilot study will help us make the final decision on these two sampling types.

The oblique trawl had the highest catch of fish per sample (Figure I.25), however, the oblique trawls were towed for ten minutes, the benthic trawls were towed for five minutes, and the neuston trawls were only towed for three minutes. The oblique trawls were being used for the larval fish study (see Chapter 2 of this report), so high fish catch was desirable for that sample type in this study. If we decide to use oblique trawls in the future, but do not want to target fish, trawling time could be reduced.

Comparing diversity across habitat types

While the major goal of our pilot sampling program was to decide which sampling types would be incorporated into our long-term monitoring program, we also gained a better understanding of how invertebrate communities vary across habitats in the Delta. Variation in invertebrate diversity across habitats is well supported in the literature. A study in China Camp marsh found that channel order, vegetation, and substrate all affected invertebrate diversity (Robinson et al. 2011). Even vegetation species within a growth form may affect invertebrate density and community diversity (Toft et al. 2003). We found the highest overall invertebrate diversity and abundance in SAV and FAV, with high densities of Amphipoda and Isopoda (see Figure I.11), similar to a study of other wetlands in the Delta by Simenstad et al. (2006). However, because SAV and FAV may not provide ideal habitat for at-risk fishes (Ferrari et al. 2014), a mosaic of habitat types on restoration sites may be optimal for fish food-web support. Each habitat we studied had its own unique community, as described below.

Emergent vegetation

There are currently no long-term monitoring programs focused on macroinvertebrates in vegetated tidal wetlands. However, there are some special studies that can put our data in context. Studies from as far back as 1968 have found that marshes dominated by tules have invertebrate communities dominated by the same taxa we found in our study (the insects *Coeagrionidae*, Corixidae, and Chironomidae, the isopod *Gnorimosphearoma*, the amphipods *Hyallela azteca* and *Americorophium spinicorne*, snails in the families Lymnae and Physidae, and the planarian *Dugesia tigrina*; Eriksen 1968). Other studies of fall-out invertebrates and neuston tows found high abundances of Collembola and Chironomidae associated with emergent vegetation in the Delta (Simenstad et al. 2013; Howe et al. 2014), similar to our sweep nets and neuston tows. The lack of other comparable studies in the freshwater reaches of the Delta highlights the need for monitoring in areas adjacent to future restoration sites and in comparison wetlands.

When examining our sweep net and leaf pack data, we found higher abundance of fish food organisms in emergent vegetation than other habitat types (Figure I.8B, Table I.7B). In other systems, invertebrates associated with emergent vegetation are particularly important to salmonid diets (Bottom et al. 2011; Roegner et al 2015; David et al. 2016), though this varies seasonally and by location. In the Delta, Sommer et al. (2001) found salmon on the Yolo bypass derived the majority of their diets from chironomid midges, which are plentiful in emergent vegetation. Delta Smelt also appear to consume more insects and amphipods when captured in areas with more emergent vegetation (Whitley and Bollens 2014; Young et al. 2016a). Increased monitoring of invertebrate prey availability in wetland regions, paired with diet analyses, will support assessment of PWT hypothesis F5: *Increased area of tidal wetlands will increase the contribution of epiphytic, epibenthic, and drift invertebrates to fish diets relative to appropriate temporal and spatial comparison data.*

Floating Aquatic Vegetation

Invasive FAV is actively controlled in the Delta, and many studies have documented its impact on water chemistry, water flow, and boat traffic (as reviewed in Villamagna and Murphy 2010). However, FAV's effect on the invertebrate community is understudied in the Delta. Other studies found high abundances of amphipods, particularly *Crangonyx*, *Gammarus*, and *Hyalella*, and high abundances of chironomid larvae on water hyacinth, similar to our results (Toft et al 2003; Donley Marineau et al. 2017). These amphipods and insect larvae may provide high-energy food for at-risk fishes (Tiffan et al. 2014). Interestingly, Toft et al. (2003) also found high abundances of terrestrial insects in the family Cicadellidae, and isopods in the genera *Ceadotus* and *Acellus*, which were rare in our samples, and Donley Marineau et al. (2017) found higher abundances of zooplankton, including Cladocera, calanoid copepods, and ostracods. This may have been due to temporal or regional differences in the invertebrate community, though the higher abundance of zooplankton could be caused by sampling differences. The benefits of these fish food invertebrates may help offset the water quality problems associated with *Eichhornia*, however native floating vegetation, such as *Hydrocotl*, often has higher overall diversity of invertebrates and higher proportion of native invertebrates (Toft et al. 2003).

Submerged Aquatic Vegetation

Like FAV, SAV is actively controlled, but few researchers have assessed invertebrate communities on SAV in the Delta. We found a lower proportion of fish food organisms on SAV than other habitat types (Figure I.8B, Table I.7B), however this varied by region, and the high total abundance of invertebrates of all kinds may mean high total abundance of fish food as well. Other researchers who have studied epifaunal invertebrates found similar communities to our study. Boyer et al. (2013) compared invertebrate communities on *Egeria densa* and *Stuckenia* spp. in Suisun Bay and the Confluence, finding high abundances of *Hyalella* amphipods, *Gnorimosphaeroma* isopods, Gastropoda, and Chironomidae, similar to our results (Boyer et al. 2013). They found that salinity, rather than SAV species best predicted the invertebrate community, though there were major changes seasonally. A similar study by Young et al. (2016a) in the Central Delta that looked at a wider variety of SAV species and also found catches dominated by *Hyalella azteca*, Chironomidae, and Gastropoda, though found fewer *Gnorimosphaeroma* than our study or Boyer et al. (2013). Amphipoda and Chironomidae may be particularly important in fish diets (Sommer et al. 2001; Whitley and Bollens 2014), so SAV may provide a source of fish food, if the fishes can access it.

Despite our findings of high fish food density, SAV has many documented negative effects on at-risk fish habitat. The recent expansion of *Egeria* and other invasive SAV reduces turbidity and provides habitat for non-native piscivores (Ferrari et al. 2014; Hestir et al 2015; Conrad et al. 2016). Fish often have decreased foraging success in vegetated habitats (Ferrari et al. 2014; Heck and Crowder 1991) and *Egeria densa* in particular decreases foraging success for Largemouth Bass over other species of SAV (Young et al 2016a). This may decrease bass's ability to prey on native species, but also may mean decreased foraging success for native species. The decreases in turbidity caused by SAV impact foraging for Delta Smelt, which decrease feeding in low-turbidity habitat (Hasenbein et al. 2013). Whether increased food production in SAV will offset the negative impacts remains to be seen.

Our SAV sampling focused on the most dominant species in the region, *Egeria densa,* and while SAV species identity does not appear to influence invertebrate community composition or density (Boyer et al. 2013; Young et al. 2016a), species identity may affect fish habitat. Further research is needed to see whether different SAV species, such as the native *Stukenia* spp., may be more desirable on restoration sites.

Benthic Infauna

While there are regular monitoring programs focusing on benthic communities, direct comparisons between our data and IEP's data are confounded by the differences in taxonomic resolution, spatial scope, and temporal scope. The only program that regularly collects benthic data (EMP) does not sample within the Cache Slough Complex (Wells et al. 2015), so many of the observed differences in community composition may be due to regional differences in invertebrate communities rather than differences in our sampling protocol. We did find that it was easy to rectify differences in taxonomic resolution by binning species into larger groups. Our samples contained fewer Cumacea and Ostracoda, and more Diptera and Copepoda. A study by Thompson et al. (2013), which included data from a number of sampling programs with wider geographic scope, found large numbers of chironomids (Diptera), oligochaete worms, and the clam *Corbicula fluminea* dominating samples from the freshwater Delta, which is similar to our general findings (Figure I.16).

Relatively high abundance of nutritious Diptera and Amphipoda in our samples, and relatively low abundance of *Corbicula* is promising for restoration in the area. However, our samples were limited in temporal scope, and benthic communities in the Delta have been found to change dramatically, both seasonally and inter-annually (Peterson et al. 2010; Thompson et al 2013; Simenstad et al. 2013). In 2017, we are expanding our sampling program to include wetlands and future restoration sites in the Confluence and Suisun areas, which are better covered by EMP, increasing our ability to compare data with these programs.

While differences between ponar grabs from EMP and our study may be due to regional differences, differences between ponar grabs and PVC cores may describe differences between shallow, vegetated habitat and channel habitat. A similar study by Howe et al. (2014) found benthic cores taken within marsh channels were also dominated by oligochaete worms, particularly in freshwater sites (polychaetes increased in abundance with salinity). However, their study did not sample in the Cache Slough Complex. The Breach II study by Simenstad et al., which examined restoration sites throughout the upper estuary, also found high abundances of Annelida, Diptera, Isopoda, and Amphipoda in benthic cores, though isopods were dominated by *Ceadota* rather than *Gnormosphearoma*. The follow-up Breach III study (Simenstad et al. 2013) used the same style of benthic core in vegetated habitat, channel, and mudflat within Liberty Island, and also found high dominance of oligochaete worms, though they found more *Corbicula* and fewer Planaria than our study.

Open Water and Channels

Comparing macroinvertebrates in our plankton trawls and other programs is particularly difficult since few programs count all macroinvertebrates in these types of samples. While mesozooplankton are widely sampled by multiple monitoring groups (20mm, FMWT, EMP), macrozooplankton are only sampled by FMWT and EMP, and these programs only quantify mysids and amphipods, not insects, and other invertebrates. The particularly high catch of amphipods in our benthic trawls may be due to high numbers of epibenthic *Americorophium*, which was the dominant genus collected in open-water sampling, and the dominant amphipod group in Delta Smelt diets (Slater and Baxter 2015). The differences in catch may be due to spatial or temporal differences, or to sampling protocol. Mysids and amphipods are strongly seasonal in their abundance, so our limited sampling time frame may have coincided with the most abundant periods for these taxa (Chigbu et al. 1998; Boyer et al. 2013).

Surface invertebrates are rarely collected from the Delta, but they may be particularly important for salmon (David et al. 2016), and are occasionally found in Delta Smelt diets (T. Bippus CDFW, pers. comm.). Data from neuston trawls is most directly comparable to the driftnet surveys from DWR's Yolo Bypass study (DWR, unpublished data), and a few special studies that have used fallout traps and neuston tows in the Delta. The BREACH III study on Liberty Island used fallout traps to quantify terrestrial input to the wetland environment (Simenstad et al. 2013). They found higher overall proportions of Diptera (Chironomidae) than our study, though had some samples dominated by Collembola and Aphididae, similar to the terrestrial portion of our neuston tows (See figure I.24). Catch of invertebrates from the Yolo Bypass was very similar to our neuston trawls (Figure I.24), with high abundances of nutritional insects often important in fish diets (David et al. 2016). The higher proportion of Diptera and Hemiptera found in their samples may be due to sampling consistently throughout the year, whereas our data came from a few discrete sampling events. Many aquatic insects "hatch" during short time spans, coming out from their benthic habitats and becoming available as they emerge as adults at the surface of the water (Merritt et al. 2008). These short periods of high abundance may be missed by only sampling once or twice per year.

Invertebrate diversity across regions

There were strong differences between the three sampling regions, despite all being within the Cache Slough Complex. This is in contrast to Simenstad et al. (1999), who found relatively small differences in invertebrate communities between sites in the Delta that were much more widely distributed than our sites. Our observed regional differences may be due to habitat factors not included in our models, such as water velocity, water source, and average depth. Thompson et al. (2013), found benthic communities in the Delta could be categorized into at least three clusters based on habitat characteristics (sediment type, vegetation, depth), rather than location *per se*. Other studies of shallow-water habitat in the Delta have found significant differences in phytoplankton and benthic invertebrate biomass that can be traced to tidal transport processes, basin geometry, and benthic substrate (Lucas et al. 2002, Thompson et al. 2013).

Fundamental differences exist between sites sampled in our study. Miner Slough is a distributary of the Sacramento River, generally characterized by lower turbidity and high flows. Lindsey Slough is a backwater slough with lower flows, characteristics that have been implicated in increased zooplankton productivity which may also apply to other invertebrates (Feyrer et al. 2017). Liberty Island is at the lower end of the Yolo Bypass, which may be a much larger source of productivity than riverine water (Sommer et al. 2004). Liberty Island also has a much larger area of open water adjacent to our sampling sites than the other two regions, with the potential for increased wind-waves and phytoplankton productivity (Lehman et al. 2015). Further research is necessary to tease apart potential causes for these differences.

Restoration Implications

This study was designed to test questions regarding sampling techniques; however, we also partially addressed one of the PWT hypotheses regarding secondary production - F3*: Form and magnitude of primary production,* *along with site and landscape attributes, will drive form and magnitude of secondary production.* We found significant differences in macroinvertebrate production that may be traced to habitat heterogeneity and could be incorporated into future restoration projects. Differences among regions and among habitats stress the importance of distributing restoration sites across the Delta, rather than locating them all in a single region. Connectivity between these restoration sites will be essential to making sure migratory fish species can access all of these diverse resources (Moyle et al. 2010; Robinson et al. 2016). Within a restoration site, construction of multiple habitat types may be more beneficial than concentrating on whichever single habitat type believed to be most important to at-risk fish species (Young et al. 2016b).

Providing a diverse range of habitats during tidal wetland restoration may increase the variety of invertebrates available for fish to eat. Fish do have dietary preferences, but many shift their diets with the abundance of local resources (Feyrer et al. 2003). For example, Mississippi Silversides collected on Liberty Island were found to consume more amphipods in open water and more insects in vegetated habitat (Whitley and Bollens 2014). Delta Smelt collected as part of IEP's channel sampling were found to consume less than 5% amphipods (by weight), and not enough insects to report (Slater and Baxter 2014). However, smelt collected on Liberty Island, where more vegetated habitat is available, were found to consume 14% amphipods and 15% insects (Whitley and Bollens 2014). An increase in invertebrates associated with vegetation as part of wetland restoration may help ameliorate declines in the pelagic zooplankton most commonly associated with smelt diets (Winder and Jassby, 2011; Kratina et al. 2014).

Increasing the relative availability of insects may be particularly helpful for increasing overall fish food quantity and quality. Insects, particularly Coleoptera and Diptera have higher energy content per gram dry mass than mysids or copepods (Tiffan et al. 2014). Many insects utilize different sources of primary production than do zooplankton, so increases in insects may be particularly important if bivalve grazers invade restoration sites. The invasive bivalve *Corbicula fluminea* did occur in our benthic samples, and while it was patchily distributed, it made up a large proportion of some samples. Other studies have found very high abundances of *Corbicula* in Cache Slough and Liberty Island (Simenstad 2013; J. Thompson USGS, pers. comm). *Corbicula* has the potential to reduce availability of phytoplankton for zooplankton grazers (Lopez et al. 2006), but may have less of an impact on the periphyton, vegetation, and terrestrial carbon that dominates carbon sources for insects in wetland habitats (Howe and Simenstad 2011; Schroeter et al. 2015; Young et al. 2016b).

Phase III and future directions

We have made progress toward establishing regular methods for long-term monitoring, however, certain questions remain. Therefore, in 2017, we will conduct "Phase III" of the FRP pilot sampling program to hone in on final sampling methods, levels of replication, and extent of comparability with long-term IEP monitoring data. We will expand our sampling to Suisun Marsh and the Confluence, with more wetland sites in each region, to hone in on minimum number of samples necessary to differentiate density and biomass between sites. We will also choose one site (Decker Island) to sample periodically throughout the year to determine the most critical sampling period for quantifying production of fish food. To better evaluate which type of trawl we should use in future, we will conduct an intensive 25-hour study of paired oblique, surface, and benthic trawls in a single location to see meso and macro zooplankton community changes vertically, and over a tidal and diel cycle. We will also sample in shallow water concurrently with the 20mm survey's channel sampling to systematically compare zooplankton catch and determine whether their data characterizes invertebrates across the entire channel. Phase III will begin baseline monitoring at future restoration sites and reference sites..

Conclusion

Through this study, we have improved our plans for long-term monitoring of macroinvertebrates in tidal wetland restoration sites. Using sweep nets in shallow and vegetated habitats, ponar grabs and benthic cores for benthic infauna, neuston tows to sample terrestrial insects, and either benthic or oblique trawls to quantify zooplankton will allow us to accurately characterize invertebrate community diversity in all wetland habitat types. We have developed some baseline information on differences in invertebrate diversity among habitat types; long-term monitoring with standard methods will increase understanding of why these differences occur, and which habitat types are most beneficial for at-risk fish species.

Part II: Fish Gear Comparisons In Tidal Wetlands

Dave Contreras, Stacy Sherman, and Rosemary Hartman

Part II: Fish gear evaluation

Project Component Lead: Dave Contreras

Introduction

Tidal wetlands provide important habitat and rearing opportunities for fish (Baltz et al. 1993; Boesch and Turner 1984; Roegner et al. 2011). Within the San Francisco Estuary, an estimated 8,000 acres of tidal wetlands will be restored. This restoration effort was mandated by the 2008/2009 Biological Opinions for Delta water project operations to restore habitat and provide food for at-risk fish species Delta Smelt, Chinook Salmon, and Longfin Smelt (USFWS 2008; CDFW (formerly CDFG) 2009; NMFS 2009). Monitoring the habitat created and changes in food production is critical to understand how tidal wetland processes could potentially affect fish rearing and growth.

Shallow water, soft substrate, narrow channels, and vegetation make monitoring in tidal wetlands difficult. No single technique can effectively sample all fish species/sizes and habitat types, as indicated by multiple published gear comparisons in shallow water habitat (Connolly 1994; Hickford and Schniel 1999; Rozas and Minello 1997). Multiple factors such as habitat obstructions, gear bias/efficiency, gear selectivity due to mesh size, practicality, cost, and Endangered Species Act (ESA) take must be considered when choosing monitoring gear types.

There are numerous fish gears available for sampling (Hayes et al., Hubert et al.; Reynolds and Kolz *in* Zale et al. 2013), but testing them all is infeasible. The Interagency Ecological Program (IEP) Tidal Wetland Monitoring Project Workteam convened a subteam of fish-centric professionals from various agencies. Over numerous meetings, they discussed which gear types should be considered for tidal wetland monitoring, but a clear consensus was not reached. Therefore, suggested gear types were chosen for the Phase I pilot study program based on their comparability to current long-term monitoring studies, ability to capture target fish species, and labor intensity.

During Phase I, various fish gear types were deployed in tidal wetlands to determine their feasibility for a subsequent rigorous gear comparison (Contreras et al. 2016, unpublished data[2]). During the Phase I study all fishing gear types (oblique larval trawl, cast net, beach seine, lampara net, Kodiak trawl, otter trawl, fyke net, electrofishing, and gill net) except for light traps were deemed acceptable for a rigorous gear comparison study. Light traps were not included in Phase II pilot work because the gear is biased towards species that exhibit a phototactic response and light trap catch-per-unit-effort (CPUE) of fishes cannot be compared to long-term monitoring studies (Choat et al. 1993; Hickford et al. 1999).

During Phase II, several fish gear types were tested within tidal wetland habitats and adjacent channels with the help of the US Fish and Wildlife Service Lodi Office (USFWS) and UC Davis North Delta Arc Program. The gear types selected for comparison were 1) oblique and surface trawls for targeting larval fish, 2) the lampara net, beach seine, and cast net for targeting juvenile and adult fish in littoral habitat, and 3) the lampara net, otter trawl, and Kodiak trawl for targeting juvenile and adult fish in channel/open water habitat. The following questions were posed for the gear comparisons:

[2] http://www.water.ca.gov/environmentalservices/docs/frpa/frp_monitoring_pilot_phase_I_final_report.pdf

1. Are the fish catches comparable between gear types?
2. Are fish lengths comparable between gear types?
3. Is fish species composition comparable between gear types?
4. Is fish diversity comparable between gear types?

Larval Trawl Gear Comparison

Methods

Study Area

Sampling sites within Liberty Island were randomly selected in February (Figure II.1) 2016. In March and April, sampling occurred outside Liberty Island at fixed sites (Figure II.1). Water depth within Liberty Island ranged from 1.5 – 2.1m, averaging 1.7m. Water depth outside Liberty Island ranged from 0.6m – 6.4m, averaging 3.8m.

Figure II.1. Larval trawl sampling sites in (circles) & around (triangles) Liberty Island.

Sampling Gear

The oblique trawls were conducted using a 15.4kg steel ski sled with a 0.40cm² mouth opening (Figure II.2). A 2m long 500 micron mesh net was strung to the sled. The net tapers down to a 7.6cm opening and attaches to a 1000mL polyethylene plastic cod end with a 10.8 x 7.6cm hole covered by a 500 micron mesh panel. A General Oceanics flowmeter was strung in the middle of the net mouth to estimate water volume. The net was towed with a 2-point Amsteel bridle behind the boat.

Figure II.2. Oblique trawl with mesozooplankton sampler.

Surface trawl gear mouth is a circular 0.5m² diameter ring and a 12.7 x 22.9cm float attached to the top of the frame to keep net from spinning in the water (Figure II.3). The 500-micron mesh net measures 2m long and tapers down toward the cod end. A General Oceanics flowmeter was strung in the middle of the net mouth to estimate water volume. The net was towed with a 3-point bridle alongside the boat. A surface trawl net was deployed on each side of the boat and will be referred to as surface trawl left (port side) and surface trawl right (starboard).

Figure II.3. Surface trawl left ready for deployment (left). Port side surface trawl deployed (right).

Sampling Procedure

Sampling occurred on Feb. 2 (n = 7), Mar. 14 (n = 6), and Apr. 28 (n = 7), 2016. Tows were 10-minutes, except in three instances where the tow was cut short due to sampling space or excessive algae in the net. Both gears were deployed at the same time, but on separate boats that were within 1000m of one another.

The USFWS boat deployed the surface trawls just below the water's surface for the entire duration of the tow (Figure II.3). Once the surface trawl nets were deployed, the CDFW boat deployed the oblique trawl sled using a 2:1 scope ratio based on water depth (i.e., 4 meters of line deployed for every 2 meters of water depth). Once the sled reached the appropriate depth, the tow began and the sled was retrieved obliquely through the water column using a pull and stop tow schedule. The tow schedule was designed to shorten the towing line by 3m at specific tow time intervals (based on sampling site depth) to sample the entire water column at equal portions.

After the tow ended, both gear types were retrieved onboard, the flowmeter reading was recorded, the net was rinsed from the outside of the mesh, and contents were washed down to the cod end (Figure II.4). The cod end was removed and the contents were poured into a pre-filled quart jar with 97mL of 37% formalin and a pinch of rose Bengal dye (Figure 4). Once the quart jar was full, the formalin was diluted to 10% and the preserved sample was processed in the lab.


Figure II.4. Surface net wash down (left) and cod end content preservation (right).

In the lab, the sample was sorted and fish were identified to the lowest possible taxonomic level using a dissecting microscope. Fish caught in surface trawls were measured to the nearest 0.1mm fork length and those caught in oblique trawls were measured to the nearest 0.5mm fork length using a stage micrometer.

Trawl catch per unit effort (CPUE) was calculated using the number of fish caught per volume water sampled (standardized to 1,000 m^3) using the following equations:

- Fish CPUE = (fish catch/water volume sampled)*1000,

- Water volume sampled = mouth opening of the net (m^2) * calibration factor of the flow meter * difference in flow meter counts from start to finish of tow.

Analysis

Four components of data were compared among the two gear types: fish CPUE, fork lengths, species composition, and diversity.

Each gear type's total tow CPUE was tested for data normality using a Wilks-Shapiro test in R 3.3.1. The results of the Wilks-Shapiro test suggested the data were not normally distributed, therefore, a Kruskal-Wallace test was run in R 3.31 software comparing total tow CPUE for each gear type (R Foundation for Statistical Computing 2016).

Length frequencies between 2.5 - 20mm were compared between the two gear types with a Kolmogorov-Smirnov (K-S) test using Past 3 software (Hammer et al. 2001). This size range represented ~97% the total number of fish caught and targeted fish size ranges. To make the data comparable, all 0.1mm fork lengths were pooled into 0.5mm groups.

Fish composition was compared between the two gear types with a one-way analysis of similarity (ANOSIM, Clarke 1993) using Past 3 software. Each tow's fish species CPUE was divided by the total CPUE for each gear type. This provided each species a percent total for each tow for every gear type. Since the surface trawls deployed two larval nets, these nets were compared to each other and each net was compared to the oblique trawl. Due to the high number of Prickly Sculpin caught in February and March, a post hoc ANOSIM test was run using April data. Sample rarefaction curves were generated using presence-absence data for each gear type to estimate species richness based on the number of sites sampled (Colwell et al. 2004). Rarefaction curves can determine the optimal number of samples to take before species accumulation levels off.

Shannon-Wiener indices were generated for every gear type's tow using each species' total CPUE. Each gear's diversity indices were tested for normality and compared using a Kruskal Wallis test. An ANOVA was completed comparing diversity indices between gear types for the month of April due to the aforementioned high number of Prickly Sculpin caught.

Results

In total, 1368 fish and 15 species of fish were collected with fork lengths ranging from 2.5 - 63mm in 20 pairs of tows. The oblique trawl captured 6 fish species and surface trawls caught 15 species (Table II.1). The three most abundant species accounted for 83% of the total CPUE between both gear types. Prickly Sculpin were the most abundant fish caught by both gear types (Table II.1). Both surface trawl nets had higher CPUEs than the oblique net; however, CPUE was not significantly different between gear types ($p = 0.94$).

Table II.1. Catch, CPUE, and fork length ranges of every species caught by each gear type. Abbreviations next to the fish species names represent those most abundantly caught by both gear types and are represented in Figure II.6. An asterisk denotes native species.

				Surface Trawl (n = 20)					
	Oblique Trawl (n = 20)			**Left Net**			**Right Net**		
Fish Species	Total Catch	Total CPUE	FL Range (mm)	Total Catch	Total CPUE	FL Range (mm)	Total Catch	Total CPUE	FL Range (mm)
American Shad							1	18.6	11.5
Bigscale Logperch	6	94.6	4 -7	1	14.5	6.3	4	66.6	5.7 - 6.3
Carp				1	14.5	6.4			
Centrarchid spp.				6	104.2	4.2 - 5.6	9	343.4	4.5 - 5.3
Golden Shiner	1	16.2	5				1	17.3	8.1
Delta Smelt*(DELSME)							1	16.0	5.4
Mississippi Silverside (MISSIL)				47	869.0	4.4 -8.2	35	719.3	4.1 - 63
Prickly Sculpin* (PRISCU)	335	5831.1	4 -12	245	4168.9	4.6 - 11	203	3915.3	4.8 - 11.2
Sacramento Blackfish*							1	17.9	7.3
Sacramento Pikeminnow*							1	19.2	14.5
Sacramento Sucker*				1	14.5	14.9	1	16.0	16.5
Splittail* (SPLITT)	2	54.5	20 -21	38	2518.1	16.4 - 28	23	615.2	13 - 27
Striped Bass				1	42.2	4.5			
Threadfin Shad (THRSHA)	52	896.0	5 -10	177	3412.7	4.5 - 13.7	156	3206.0	4.6 - 12.4
Tridentiger spp. (TRISPP)	92	1765.6	2.5 -5.5	15	219.4	2.7 - 4.2	18	761.2	3 - 5.2

There was no significant difference between the mean fork length of the fish caught in the oblique and left surface trawl ($p = 0.46$) or right surface trawl ($p = 0.10$) or between surface nets on the same boat ($p = 0.97$). However, surface trawls caught a wider range of fish lengths than oblique trawls (Table II.1) and a higher number of fish greater than 6mm (Figure II.5). Looking at general patterns of fish catch by month, it appears both gear types captured similar fish species from February to March (Figure II.6). However in April, fish species catch appeared to diverge among gear types (Figure II.6).

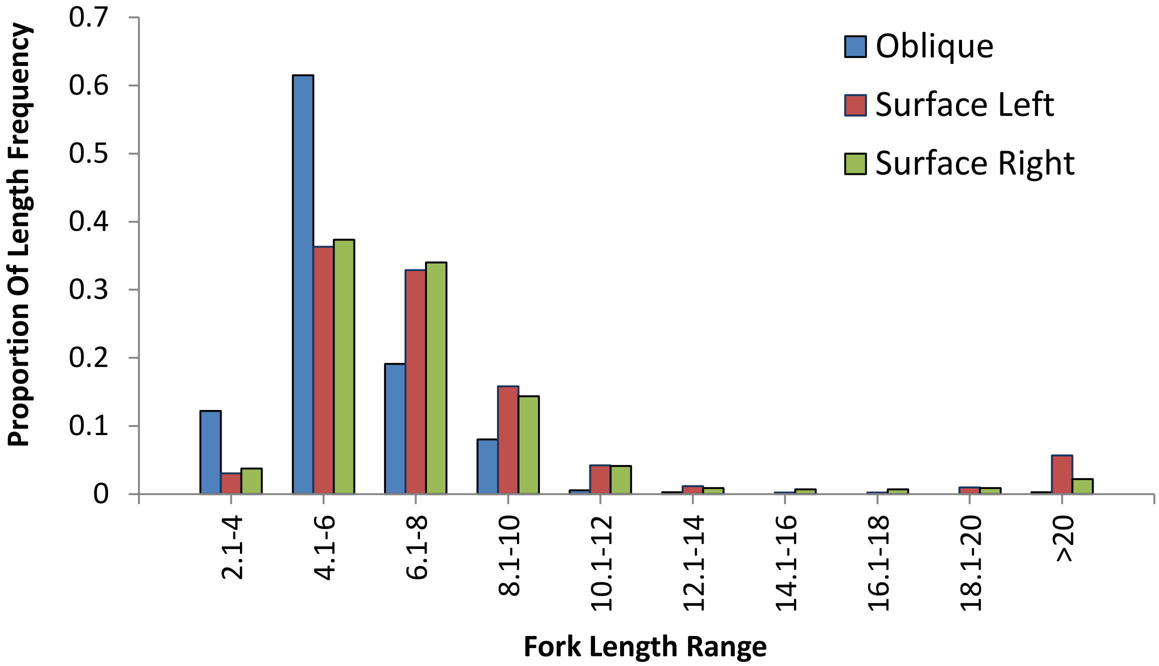


Figure II.5. Fork length ranges of fish caught by each gear type. The K-S test was performed between lengths 2 – 20mm.

Fish composition did not differ when considering all samples taken from February through April (R = 0.002, p = 0.39). However, during the month of April alone, fish composition differences occurred between the oblique trawl and the surface trawl left net (R = 0.21, p = 0.01), and between the oblique trawl and surface trawl right net (R = 0.32, p = 0.01). Sample rarefaction curves estimated higher fish species richness in surface trawls (Figure II.7). However, fish diversity indices did not differ between gear types for February – April (F = 0.43, p = 0.81) or in April exclusively (F = 0.76, p = 0.48) (Table II.2).

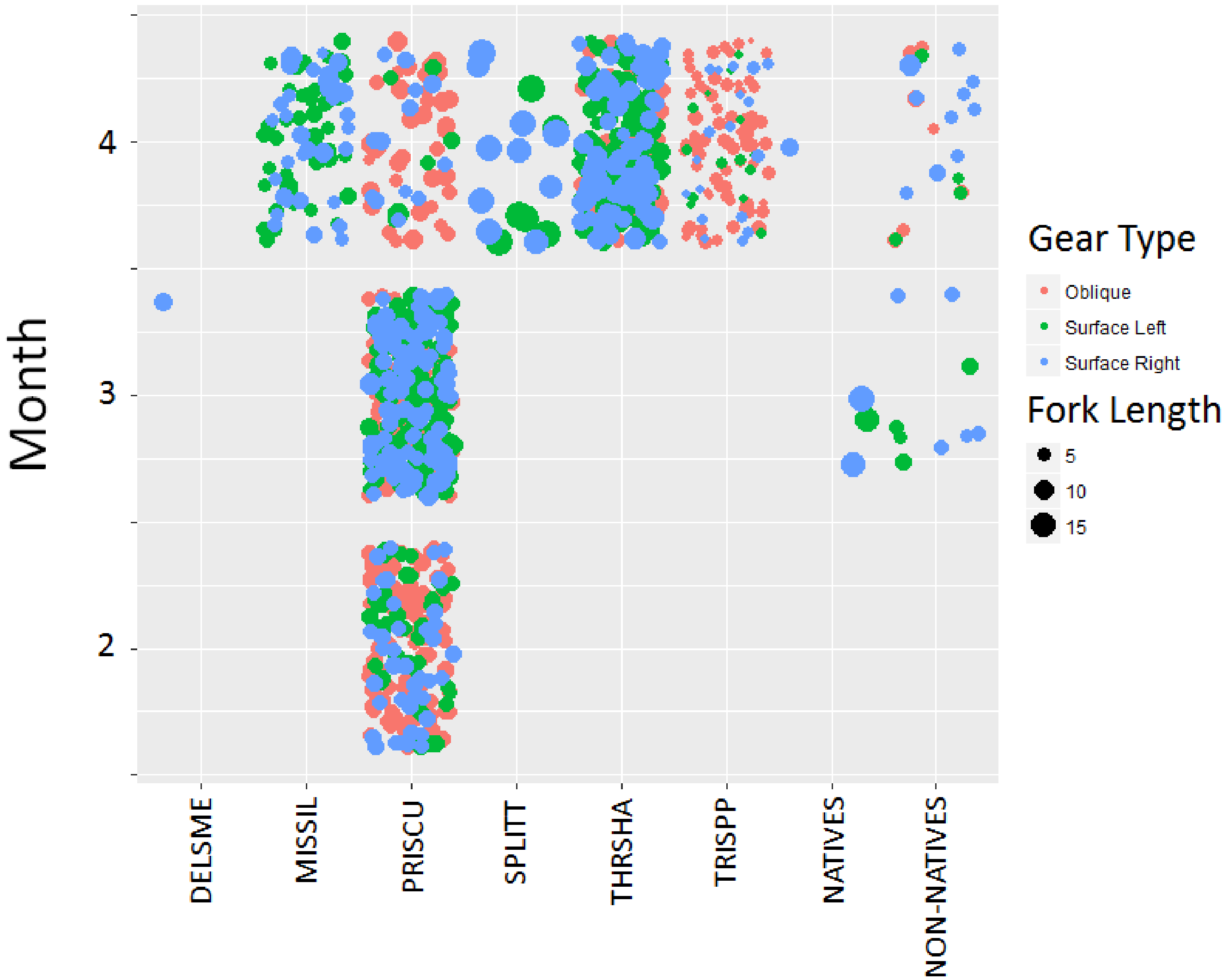


Figure II.6. The most abundant fish species caught each month, where each dot represents a fish caught and the size represents the fish size for each gear type. Natives and Non-natives represent groupings of other fish.

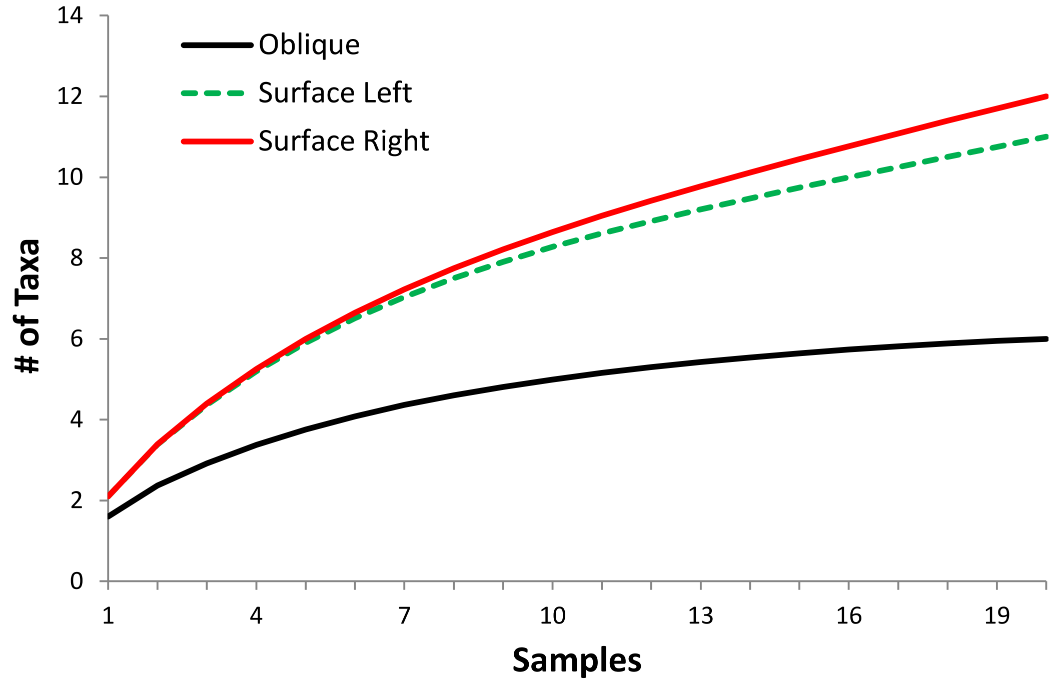


Figure II.7. Sample rarefaction curves for the surface trawls and oblique trawl.

Table II.2. Mean Shannon-Wiener diversity index and standard error values for two sampling periods.

Gear	February - April		April	
	Mean Diversity Index	**SE**	**Mean Diversity Index**	**SE**
Oblique Trawl	0.31	0.11	0.79	0.17
Surface Left Trawl	0.29	0.10	0.65	0.19
Surface Right Trawl	0.38	0.11	0.96	0.16

Discussion

There were no significant differences in fish abundance, size, or diversity between the two gear types. Although fish compositions were similar when analyzing all sampling months, this was likely the result of the high number of Prickly Sculpin caught in February and March (Figure II.6). In April, the oblique trawl caught more demersal species such as gobies and sculpins, and surface trawls captured more pelagic species such as shad, silversides, and cyprinids (Figure II.6). Based on how the gears were towed, the data suggests that the placement of a trawling net behind a boat may influence fish species catch at the water's surface. For example, during one sampling event, a 10-minute oblique trawl (net was towed behind the boat) captured 14 Threadfin Shad, while a 3-minute neuston trawl (net was towed off the side of the boat at the water's surface) caught 22 Splittail and 9 Mississippi Silversides (See Macroinvertebrates chapter). This may suggest boat bow disturbance causes pelagic larval fish movement or displacement. Since we do not know the true vertical distribution of larval fish in the water column, we can only speculate that the wake from the bow may push larval pelagic fish off to the side of the boat, causing a higher number of pelagic fish to be caught in the surface trawl (Figure II.8). Claramunt et al. (2005) compared a push net with a trawl and suggested that boat disturbance and sound influence larval fish catch. Larval fish may also actively swim under the boat or to deeper waters. Boat disturbance may be a possible explanation as to why the surface trawl and the neuston tow caught more pelagic fishes.

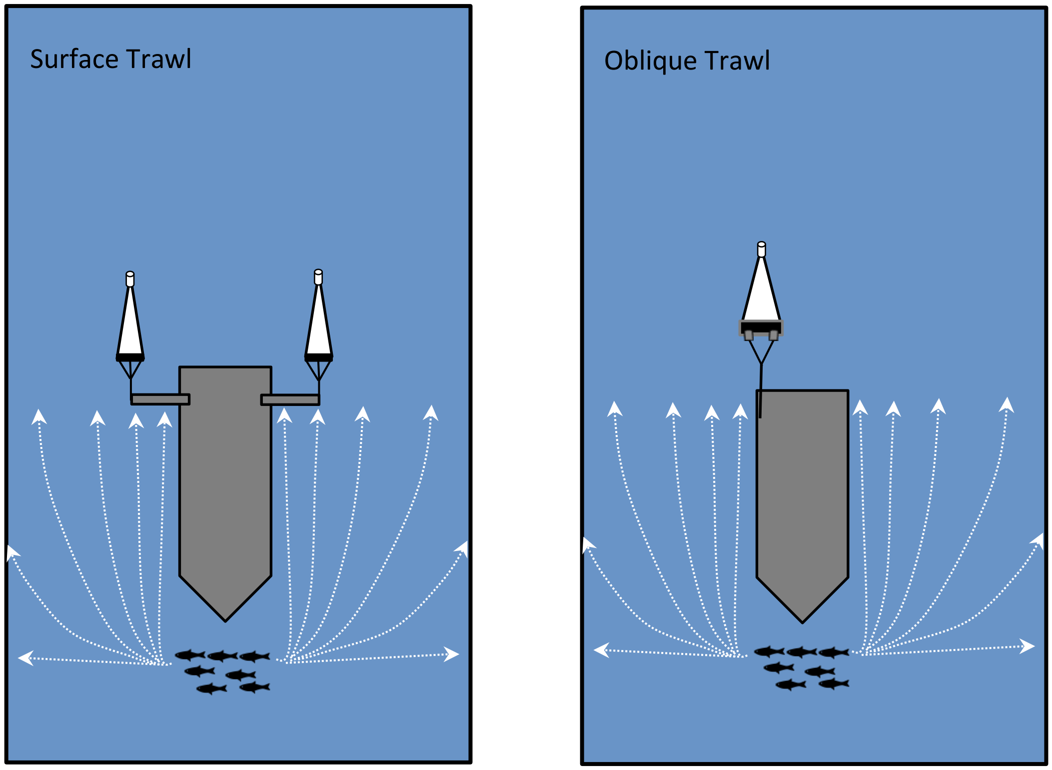


Figure II.8. Overhead two-dimensional mock example showing the potential direction larval fish (represented by dotted white lines with arrows) at the bow of the boat may occur in relation to the sampling nets. Arrows closest to the boat are more likely fish swimming/boat displacement paths as the boat trawling speed is much greater than larval fish swimming speed.

As expected, the number of larval pelagic fish species caught was greater in the surface trawls due to the amount of time each net spent at the water's surface. The deployment of two larval fish nets at the water's surface improved the detection of rare larval fishes such as Delta Smelt and other seldom caught native species (Table II.1). Since the oblique trawl towed throughout the water column, only a portion (or approximately 3 minutes) of the tow was spent at the water's surface. The proportion of time the oblique tow spent at various depths in the water column can be used to extrapolate abundances. However, inferences would need to be made as to where the fish were caught within the water column since both gear methods would likely not occur at the same time.

After analyzing the fish catch, lengths, diversity, and composition we recommend using surface trawls for sampling larval fish. Surface trawling predicted higher species richness and may improve the detection of rare larval species such as Delta Smelt by sampling one water stratum. Additionally, surface trawls are simpler to deploy and typically do not have snagging issues. Surface trawls appear to provide the necessary information to determine whether at-risk native fish are rearing within wetland habitats.

Littoral Habitat Gear Comparison

Methods

Study Area

Littoral habitat sampling in Liberty Island occurred at established sites that the USFWS samples each month (Figure II.9). Monthly sampling occurred from January to September 2016 for a total number of 27 comparable samples. Sampling sites were typically void of vegetation with substrates composed of gravel, sand, and mud mixtures.

Figure II.9. Littoral habitat sampling sites in Liberty Island

Sampling Gear

The lampara net is a tapered net measuring 65m long x 3m high. The cod end is composed of 9.5mm stretch mesh and connects to two wings composed of variable stretched mesh (76, 153, and 89mm, Figure II.10). Larger mesh sizes are used in the wings to reduce net weight, allow the net to be hauled quicker, and reduce back injury. The cod end flooring material is composed of various stretched mesh sizes (9.5, 12.7, and 76.2mm). Bao-Long BL-S floats were placed approximately every 0.6m on the 11.3mm thick float line and the 22.7kg/110 fathom lead line contains 56.7g lead weights spaced approximately 25mm along the floor material.

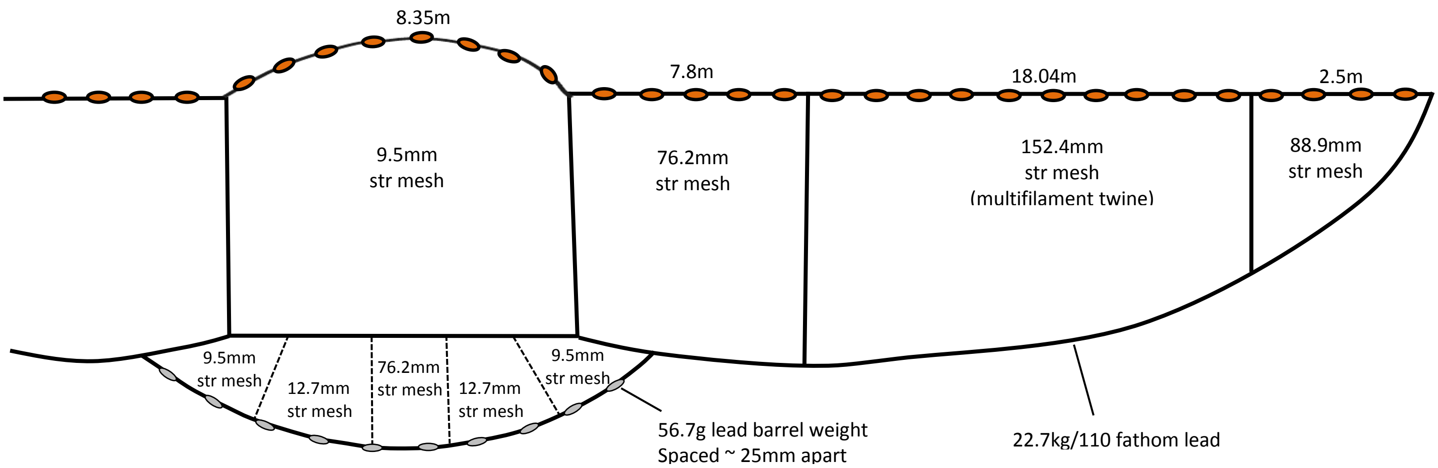


Figure II.10. Lampara net showcasing dimensions for one wing and the cod end bag (str mesh = stretched mesh).

The beach seine measures 15m long x 1.2m high and is composed of 3mm delta square mesh (Figure II.11). The net has floats every 0.5m along the top line and a weighted lead line. A 1.8m high wooden pole attaches to each side of the beach seine net.

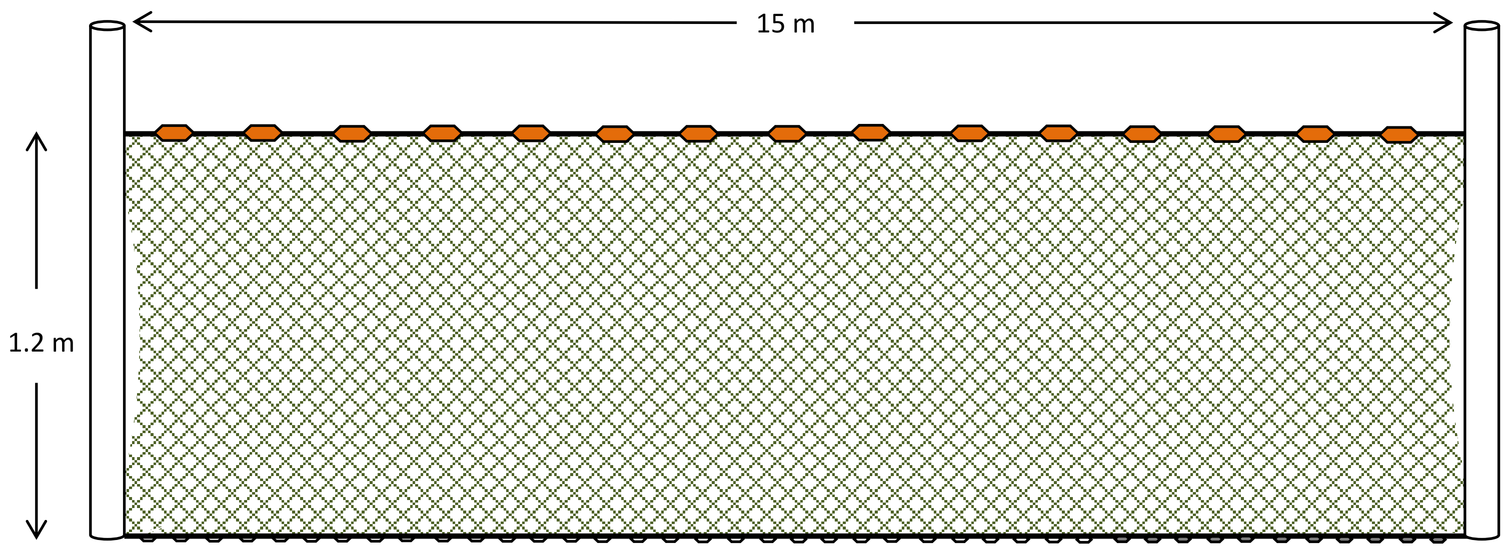


Figure II.11. Visual beach seine specifications.

The cast net has a 2.4m diameter mouth opening, weighs 1814.3 g, and is composed of 19mm monofilament stretch mesh (Figure II.12). The bell of the cast net attaches to a throwing ring, allowing the thrower to ensure the net opens correctly and consistently. Bray lines run from the lead line up through the bell, and attaches to a 7.9m polyethylene throwing line.

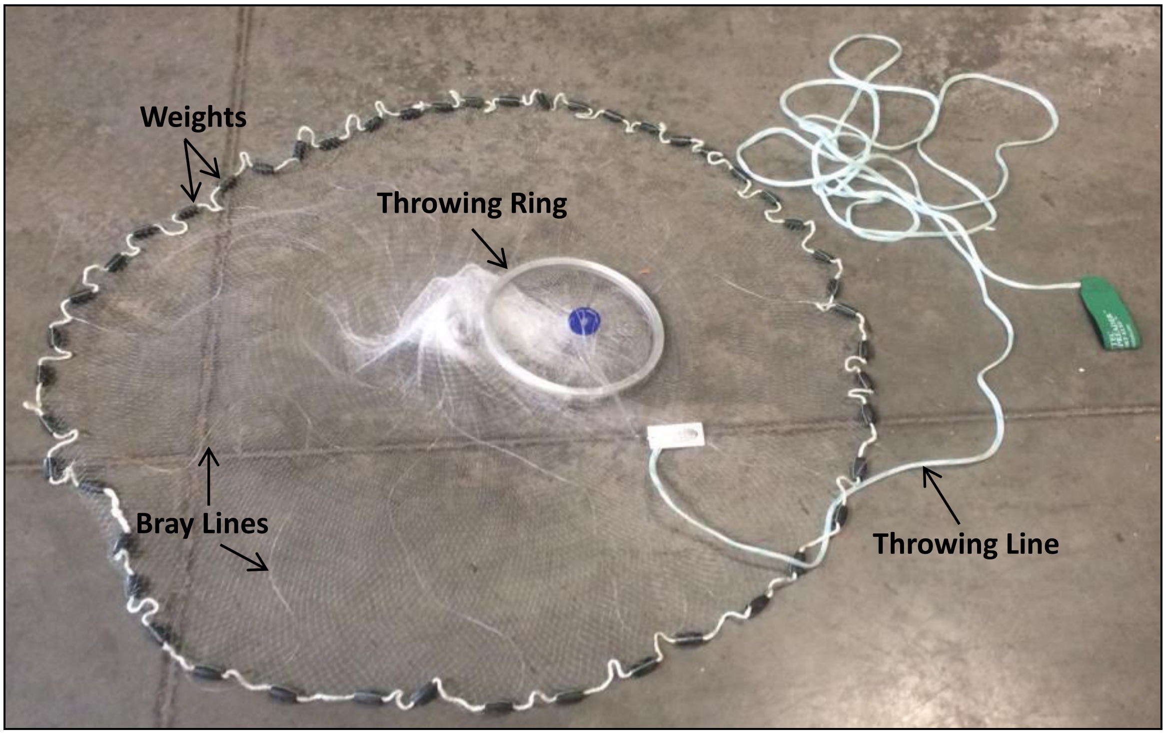


Figure II.12. Parts of a cast net.

Sampling Procedure
At each sampling site, the cast net was deployed after the lampara net. The cast net was only deployed during March (n = 28) because few fish were caught during the Phase I pilot study. Due to the cast net's consistent low fish catch, cast net sampling stopped and data were removed from the analysis.

The lampara net and beach seine were not fished simultaneously due to the size of seine-able beaches, so gears were deployed between 24-48 hours of one another. This allowed both gears to sample around the same tidal phase while minimizing fish disturbance effects from the previous sampling effort. The number of comparable samples varied each month due to various circumstances (vegetation, people fishing on the seine site, beach under water). Sampling occurred during January-April, June, and August-September in 2016.

The beach seine was deployed from shore by crewmembers. One crewmember walked perpendicular from shore into the water holding one end of the net until a depth appropriate for proper seining was reached (Figure II.13A). A second crewmember followed the path of the first crewmember to minimize site disturbance and positioned their seine pole upon reaching the first crewmember. The first crewmember then turned parallel with the shore and continued walking until the seine was fully opened (Figure II.13B). Water depth and seine length were recorded before both crewmembers pulled the seine towards the beach at a similar speed until only the cod end bag remained in the water (Figure II.13C). The crew filled a tub with water and placed the cod end in the tub along with any fish caught in the wings of the seine. Thirty individuals of each fish species were measured to the nearest millimeter fork length and all remaining fish were enumerated. Fish CPUE was calculated using the number of fish caught per volume water sampled (standardized to 10,000 m^3) using the following equation: (fish catch/ (½Depth x Width x Length of seine site))*10000.

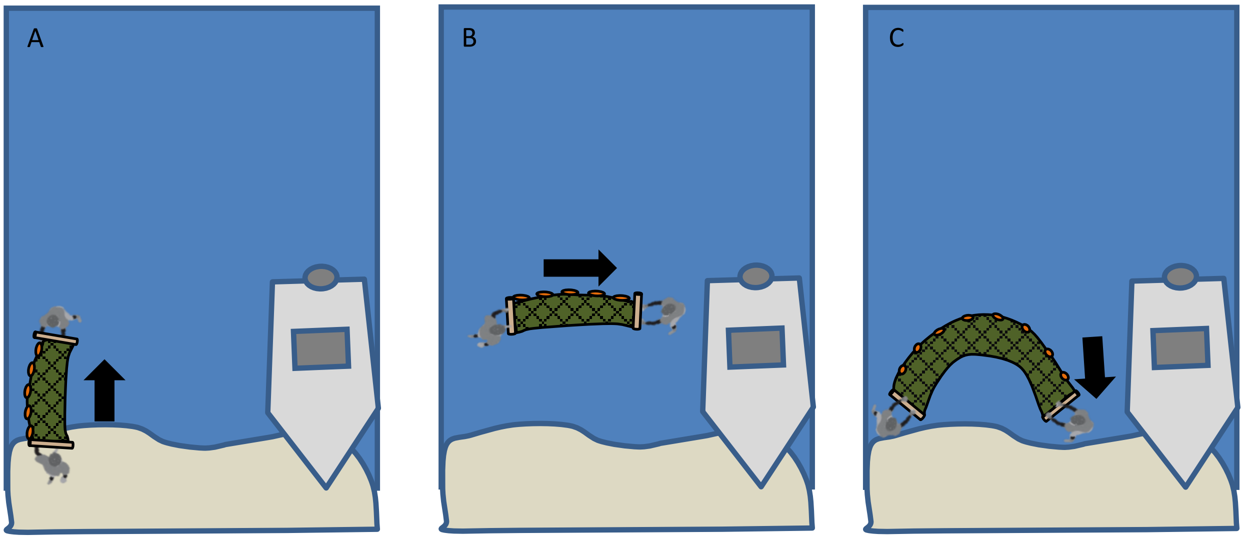


Figure II.13. Overhead view of beach seine deployment. Gray shape on the right of each picture represents a boat.

The lampara net was deployed using a boat or by hand, depending on vegetation and accessibility of the site. When the lampara was set by boat, the boat drove up to shore on one side of the site. A crew member was left on the shore edge holding one side of the lampara net (Figure II.14A), while the boat backed away from shore and onboard crew deployed the gear in a circular pattern around the site (Figure II.14B). Once the net was fully deployed, the boat made its way to the other side of the site and a second crewmember, holding the other end of the net, stepped off of the boat. Both crew members walked toward one another and hauled the lampara net up on shore leaving the cod end bag in the water (Figure II.14C). The crew filled a tub with water and placed the cod end bag in the tub along with any fish caught in the wings of the lampara net. Thirty individuals of each fish species were measured to the nearest millimeter fork length, and all remaining fish were enumerated.

When a site was inaccessible by boat, the lampara net was deployed by hand by three crewmembers. The first crewmember walked perpendicular from shore to a depth of up to 1.2m while holding one side of the lampara net. The first crewmember pulled approximately 2/3 of the entire net and stock piled it where they are standing, leaving the one wing perpendicular to the shore in the water. A second crewmember entered the water and walked to the first crewmember. The first crewmember then walked around the seine site in a circular fashion, still holding the end of the net, while the stockpiled portion of the net was deployed by the other crewmember. Once most of the net was deployed, both crewmembers walked back to shore and each hauled in a lampara wing as described above. Thirty individuals of each fish species were measured to the nearest millimeter fork length, and all remaining fish were enumerated.

Both gear types were deployed in non-vegetated littoral habitats.

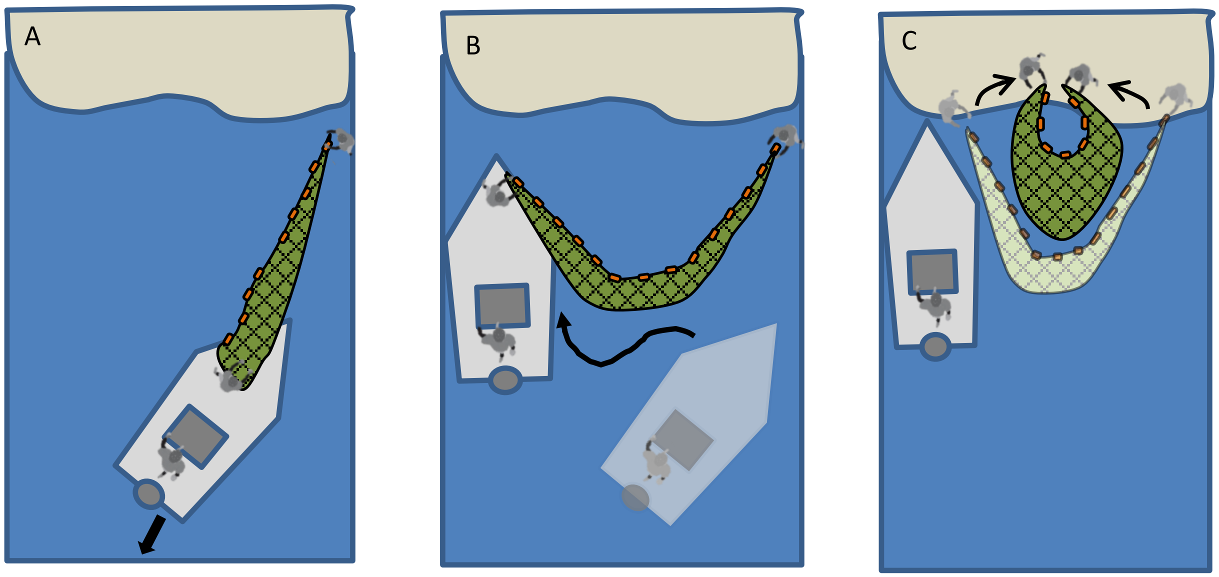
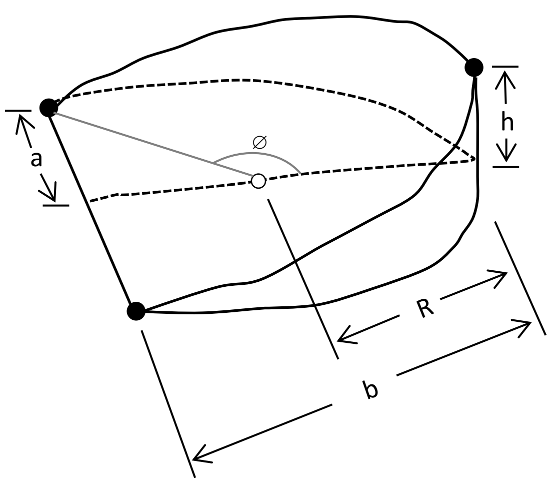


Figure II.14. Overhead view of how the lampara is deployed by a boat.

Fish CPUE was calculated using the number of fish caught per volume water sampled (standardized to 10,000 m^3) using the following equation: (fish catch/(volume))*10000. The volume of water sampled was determined using the volume of a cylindrical wedge (Figure II.15). Since length "b" is not recorded in field, this length is estimated based on length "a". This was accomplished by increasing length "a" in five meter increments (5 - 40m) on a field in a u-shape. The corresponding length "b" was recorded for each five meter increment. The volume and values "R" and "∅" were calculated using equations provided by Harris and Stocker (1998).



$$R = \frac{(a^2 + b^2)}{2b}$$

$$\varnothing = \frac{1}{2}\pi + \tan^{-1}\left[\frac{b - R}{a}\right]$$

$$V = \frac{h}{3b}\left[a(3R^2 - a^2) + 3R^2 (b - R)\varnothing\right]$$

Figure II.15. Volume of a cylindrical wedge used to calculate the amount of water sampled by the lampara net.

Analysis

Four components of data were compared among the two gear types: fish CPUE, fork lengths, species composition, and diversity.

Each gear type's total seine CPUE was tested for normality using a Wilks-Shapiro test. The results of the Wilks-Shapiro test suggested the data were not normally distributed, and gears were compared using a Wilcoxon rank-sum test in R (R Foundation for Statistical Computing) software comparing total tow CPUE for each gear type.

Length frequencies between 20 - 100mm were pooled into 5mm groups for both gear types and compared using a Kolmogorov-Smirnov (K-S) test in Past 3 software (Hammer et al. 2001). This size range represented 95 - 98% of the total catch for both gear types and represents the target size ranges.

Based on results from a cluster analysis using environmental data and fish seasonality site use, fish composition was compared for two periods: January through April, and June through September. Each sampling site's fish species CPUE was transformed into a percent catch based on the total CPUE of each gear type. Using the percent catch of each species caught per tow, a one-way analysis of similarity (ANOSIM, Clarke 1993) was used to test if differences of fish composition occurred between gear types using Past 3 software. Sample rarefaction curves were generated using presence-absence data for each gear type to estimate species richness based on the number of sites sampled (Colwell et al. 2004). Rarefaction curves can determine the optimal number of samples to take before species accumulation levels off. Shannon-Wiener indices were generated for both gear types using each species' total CPUE from each sample. Diversity indices were tested for normality using a Wilks-Shapiro test and compared to one another using a Mann-Whitney U test.

Results

A total of 2,190 fish and 25 fish species were collected with fork lengths ranging from 20 – 484mm from 27 pairs of beach and lampara seines (Table II.3). Approximately 74% of the total beach seine's CPUE was composed of Mississippi Silverside, Splittail, and Chinook Salmon. Eighty-four percent of the total lampara net CPUE consisted of Mississippi Silverside, Striped Bass, and Shimofuri Goby. Target species Chinook Salmon were caught by both gear types and one Delta Smelt was caught by the lampara net. The total CPUE for the beach seine was higher than the lampara net and showed a significant trend ($p = 0.06$), as higher beach seine CPUE values occurred in 69% of the comparable sampling sites.

Table II.3. Catch, CPUE, and fork length ranges of every species caught by each gear type. Abbreviations next to fish species names represent fish species caught by both gear types presented in Figure II.17. Please note that Carp were counted but not measured due to their large size potentially injuring smaller fish if placed in the sorting tray.

	Beach Seine (n = 27)			Lampara Net (n = 27)		
Fish Species	Total Catch	Total CPUE	FL Range (mm)	Total Catch	Total CPUE	FL Range (mm)
American Shad (AMESHA)	1	55.6	66	25	1563.0	24 - 97
Bigscale Logperch (BIGLOG)	3	592.6	86 - 108	4	194.2	60 - 117
Bluegill (BLUEGI)	12	5433.8	25 - 176	13	507.3	23 - 161
Brown Bullhead				1	50.5	246
Channel Catfish				2	143.8	412 & 432
Chinook Salmon (CHISAL)	43	8026.0	33 - 67	4	153.8	39 - 52
Carp*				5	343.2	-
Delta Smelt				1	26.6	69
Golden Shiner (GOLSHI)	1	66.7	42	32	1212.5	39 - 169
Largemouth Bass (LARBAS)	5	563.0	93 - 300	25	964.4	48 - 224
Mississippi Silverside (MISSIL)	608	41129.9	25 - 98	864	58127.9	21 - 111
Mosquito Fish (MOSQUI)	5	3254.0	20 - 27	3	118.5	23 - 30
Prickly Sculpin (PRISCU)	1	694.4	88	5	178.1	35 - 75
Redear Sunfish (REDEAR)	10	5777.8	27 - 79	39	1593.0	26 - 225
Sacramento Pikeminnow (SACPIK)	10	2083.4	63 - 207	7	406.8	62 - 202
Sacramento Sucker				2	73.5	38 & 484
Shimofuri Goby (SHIGOB)	15	1340.8	42 - 69	55	4337.7	38 - 90
Splittail (SPLITT)	103	25080.8	25 - 63	50	3652.2	34 - 168
Spotted Bass	1	242.4	113			
Striped Bass (STRBAS)	113	5543.4	25 - 98	86	5905.0	23 - 340
Threadfin Shad				27	1782.7	26 - 96
Tule Perch				3	113.4	132 - 150
White Catfish				1	68.6	463
White Crappie				1	36.0	297
Yellowfin Goby (YELGOB)	1	66.7	78	3	124.6	105 - 127
Total	932	99951.1	N.A.	1258	81677.3	N.A

There was no significant difference in fish lengths (p = 0.26) between gear types. Approximately 89% of fish caught by the beach seine had lengths between 20 – 69mm and 90% of the fish caught by the lampara net had fork lengths ranging from 20 – 79mm (Figure II.16). The beach seine caught a higher percentage of fish less than 50mm including smaller Chinook Salmon and Splittail. The largest fish measured by the beach seine and lampara net were 300mm and 484mm, respectively. The range of lengths caught by the lampara net appears to have greater spread than the beach seine based on the most abundant fish species caught by both gear types (Figure II.17).

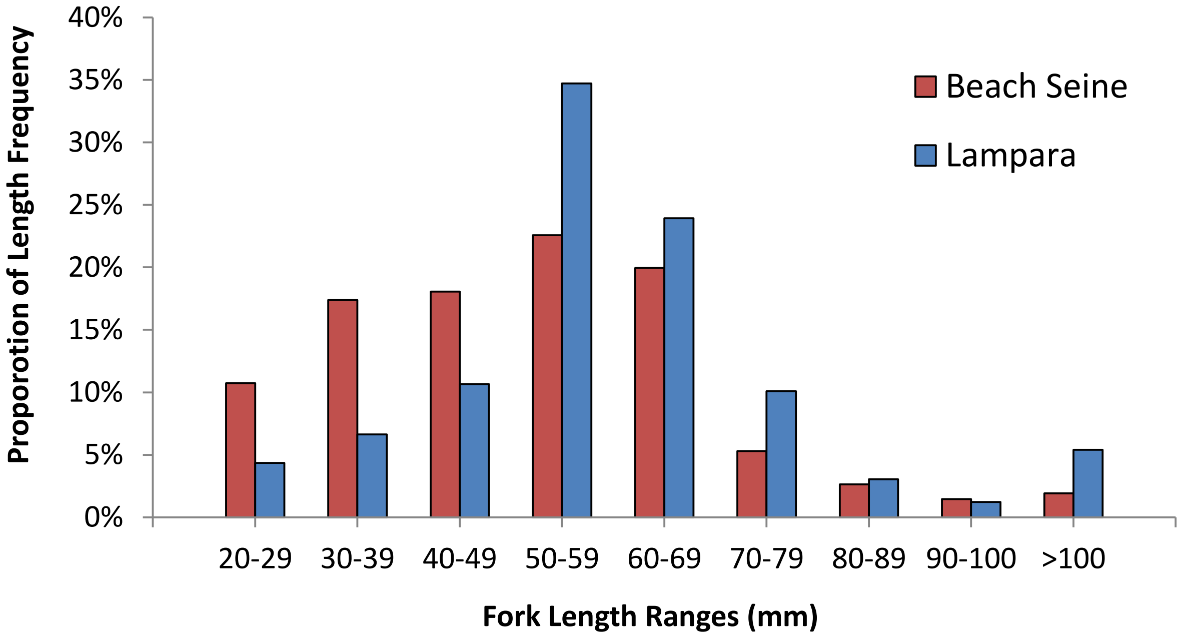


Figure II.16. Fork lengths caught by each gear type. Fish greater than 100 mm were not used for length comparisons between gear types, but are shown here for additional information.

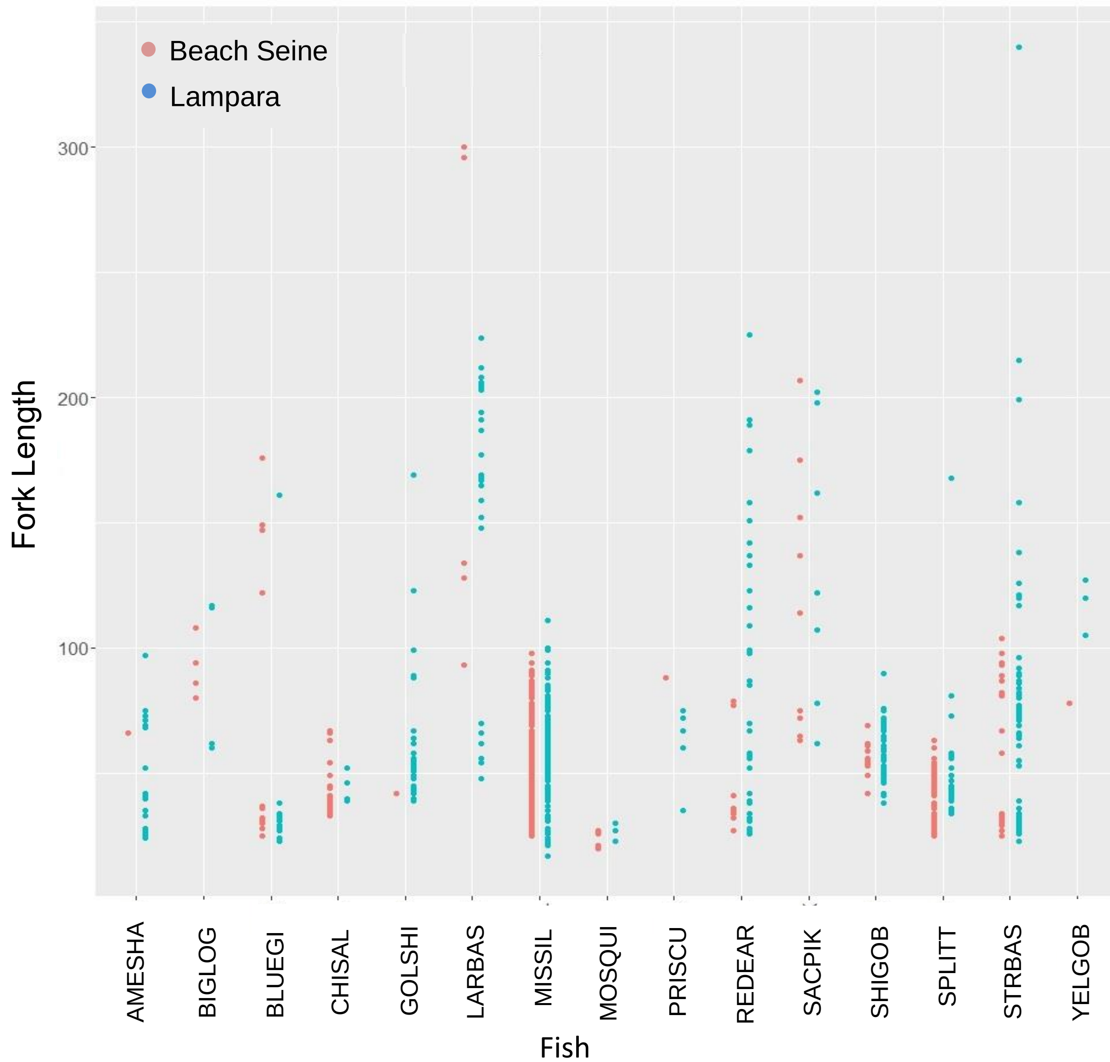
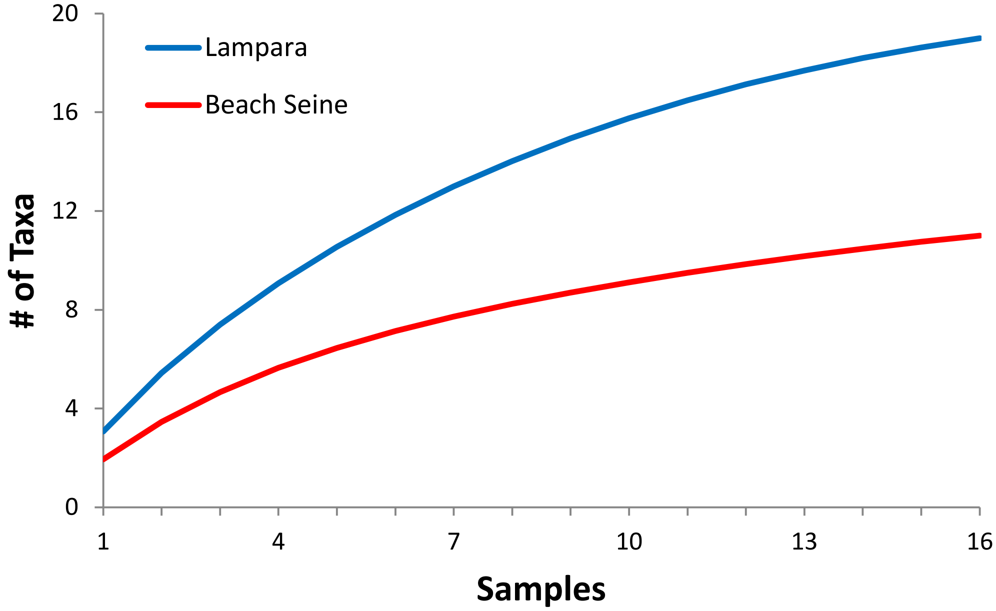


Figure II.17. Measured fork length ranges of the beach seine and lampara net. Each dot represents an individual fish. Species codes are as listed in Table II.3.

Although more fish species were caught with the lampara net than the beach seine, there was no significant difference in fish composition between gear types during Jan – Apr (R = 0.04, p = 0.17) and June, August, and September (R = 0.03, p = 0.20). However, rarefaction curves estimate the lampara net catching more fish species with fewer samples, especially during January through April (Figure II.18). Fish species diversity differed between both gear types (Z = -2.7712, p = 0.01) and diversity was higher for the lampara net (Table II.4).



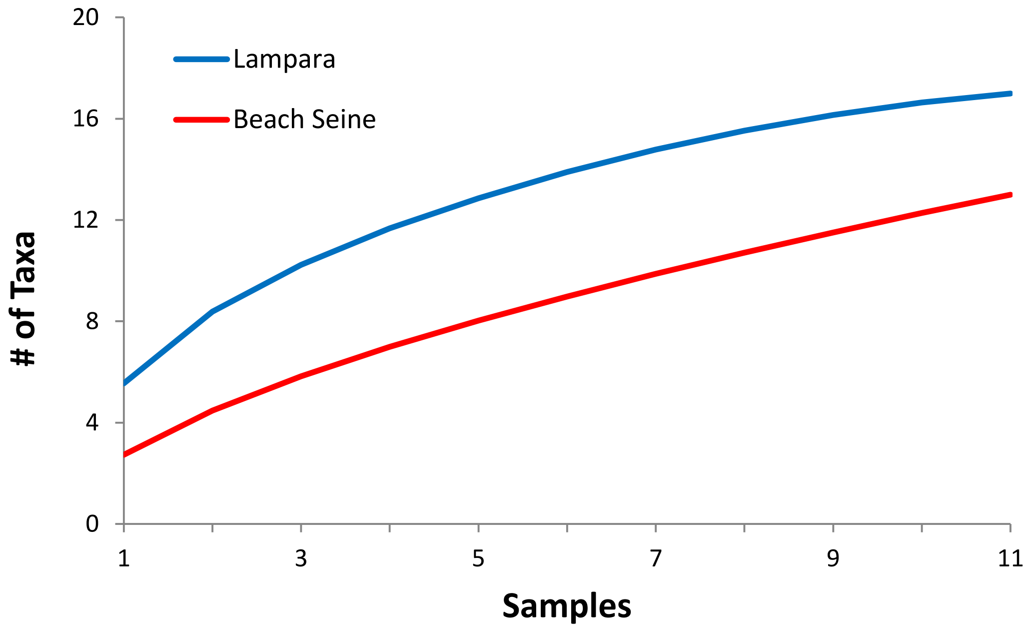


Figure II.18. Sample rarefaction curves for Jan-April (top) and June, August, September (bottom) showing the expected number of fish species to be captured based on the number of samples conducted for each gear type.

Table II.4. Mean Shannon-Wiener diversity index and standard error values.

Gear	Mean Diversity Index	SE
Beach Seine	0.49	0.09
Lampara	0.88	0.10

Discussion

Catch differences between the beach seine and lampara net are likely attributed to gear length, mesh size, and how each gear is deployed. As mentioned before, the lampara is ~4.3 times longer and composed of larger variable mesh sizes than the beach seine. The lampara net samples a larger volume of water, improving the detection of fish species that may be on the outskirts of smaller nets (Figure II.19). Fish species exclusively caught by the lampara net were typically larger (Table II.3) and probably caught in deeper water outside of the sampling range of the beach seine (Figure II.19). Similar results were reported in other studies suggesting net length increases the detection of fish species, larger fish sizes, and efficiency (DeLacy and English 1954, Riha et al. 2008).

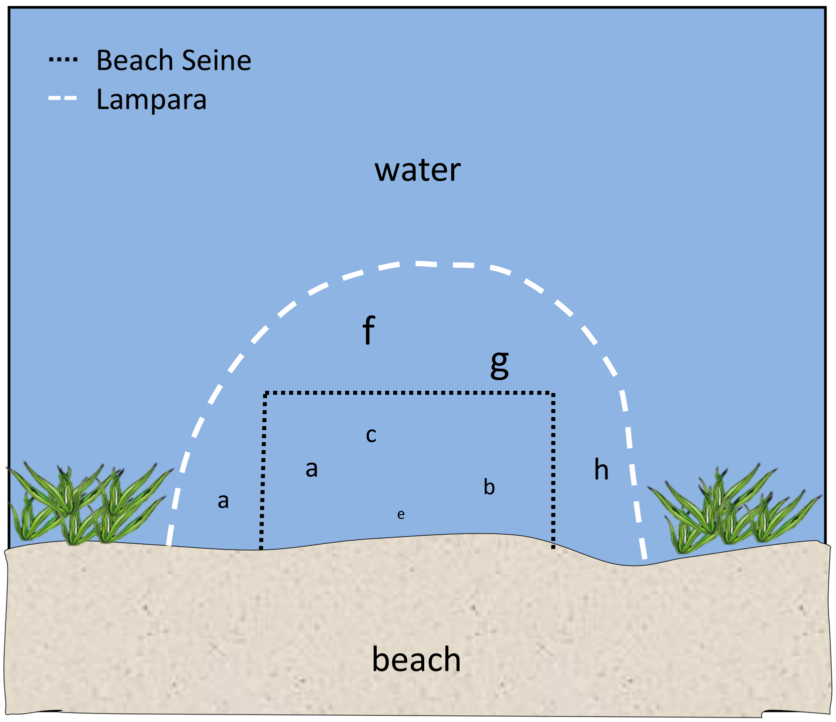


Figure II.19. Overhead mock diagram showing fish species location (represented by letters) and volumes of water sampled by each gear type (represented by dotted and dashed lines). Size of the letters represent fish size (larger font size = larger fish).

However, net length can also hinder sampling a multitude of ways. Since Liberty Island was an agricultural farm before it was accidently breached, numerous snags occur on trees, rip rap, or farming equipment and confound sampling. Lampara seining took more time and was more variable than the beach seine. Nearly half of the lampara seines were listed as having a minor snag. The beach seine recorded no issues with snags. Minor snags consume time, as people hauling the net from shore need to trace the snag in the water and carefully free it. The time spent freeing net snags allows smaller sized fish to escape through the larger meshes present in the wings of the lampara net.

Although the lampara net is much larger than the beach seine, some fish species were caught more frequently in the beach seine. Target species Chinook Salmon and fish species of interest Splittail were caught more frequently in the beach seine. This is likely due to small sized fish swimming through the large mesh panels in the lampara net wings. To illustrate this point, in August one lampara seine was taken through vegetation and filled with aquatic vegetation and filamentous algae (please note that this data was not used in comparing gear types because no comparable beach seine occurred). The aquatic vegetation may have formed a barrier preventing fish from escaping through the wings of the lampara net. This tow captured 11 species of fish and 3,124 individuals (~96% of this catch was Mississippi Silversides, see Appendix B). Although it is unknown whether the high number of fish caught was due to the number of fish inhabiting vegetated habitat, vegetation preventing fish from escaping the net wings, haphazardly catching a large school of Mississippi Silversides, or a combination of these three factors, it is worth noting that one lampara seine caught 1.4 times more fish than the combined 27 pairs of beach and lampara seines presented in this study. Sampling through vegetation is cumbersome and difficult to accomplish, but may yield important information about fish composition in vegetated littoral habitat (Conrad et al. 2016, Mahardja et al. 2017, Young et al. 2016).

The advantages and disadvantages of each gear type were considered when choosing which gear type to use in wetland littoral habitat. Since tidal wetland littoral sampling space will likely be limited, shallow, and difficult to sample using a boat, we recommend using a beach seine. The beach seine not only had a higher CPUE, but also caught more native fish such as Chinook Salmon and Splittail. However, a smaller lampara net can be used as a supplemental method when the beach is inundated, sampling in vegetation, or on the outskirts of vegetation.

Channel Habitat Gear Comparison

Methods

Study Area

Sampling occurred in Lindsey and Barker sloughs at sampling sites established by the UC Davis Arc study. This area is particularly interesting because in 2014, 965 acres of tidal wetland was restored in Lindsey Slough by CDFW. The one-mile channel was restored along the southern arm of the slough that had been cut off for more than 100 years. The northern arm upstream of Calhoun Cut was enlarged at the breach opening.

Sampling occurred from January to March and June 2016 (Figure II.20). Sampling did not occur in April and May, and the Kodiak trawl was excluded in June due to time conflicts and/or boat issues.

Figure II.20. Sampling sites in Lindsey and Barker sloughs for all three gear types. The orange lines represent two sections that are restored to tidal wetland habitat.

Sampling Gear

The Kodiak trawl measures 17m long and has a 4.9m x 1.8m mouth opening. This Kodiak trawl net mouth is approximately 18% smaller than the one used by CDFW's Spring Kodiak Trawl survey. The net consists of 4 panels that graduate down to 6mm str. mesh (41mm, 25mm, 13mm, and 6mm). Each mouth net side was attached to an aluminum spreader bar with a float at the top and a 4.53kg weight on the bottom (Figure II.21).

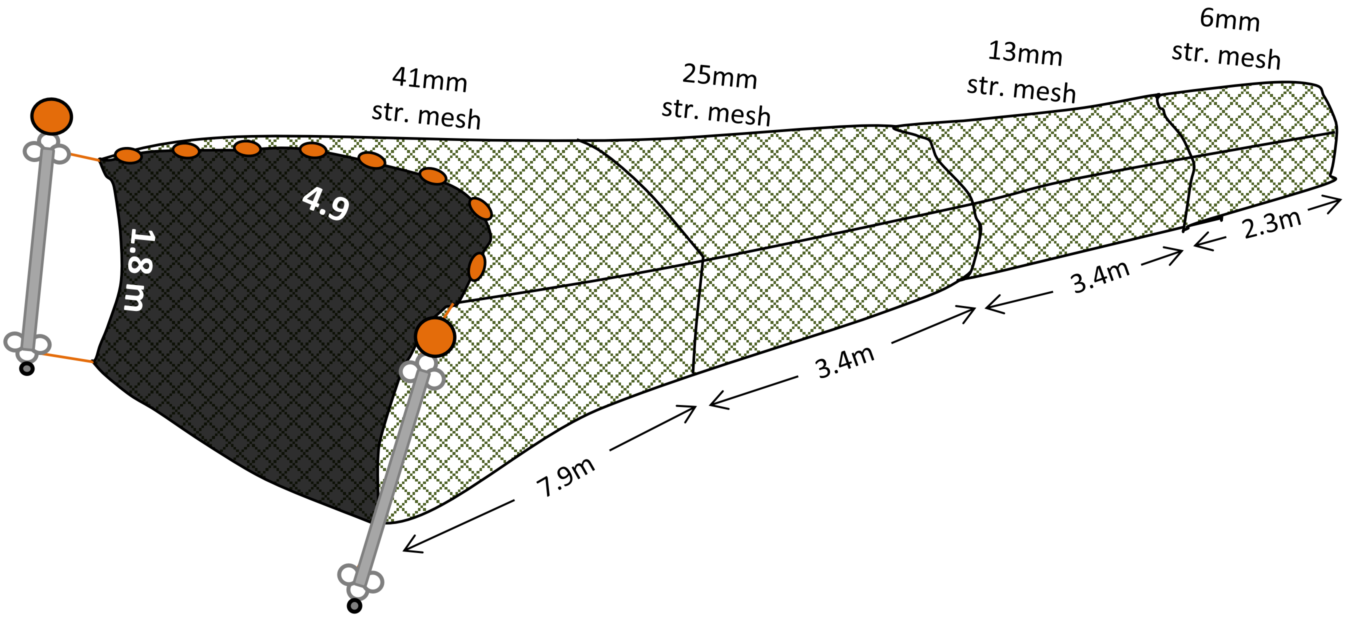


Figure II.21. Kodiak trawl net dimensions attached to spreader bars.

The otter trawl is a 5.3m long net and has a 4.3 x 1.5m mouth opening. The net is composed of 3.8cm stretch mesh in the body of the net and narrows down to a 0.32cm stretch mesh cod end. A 0.64 stretch mesh panel surrounds the cod end to prevent chaffing. Each side of the net mouth was connected to a 1.9cm thick plywood door with steel runners. The door dimensions are 38.1 x 76.2cm and each weighs 10kg (Figure II.22).

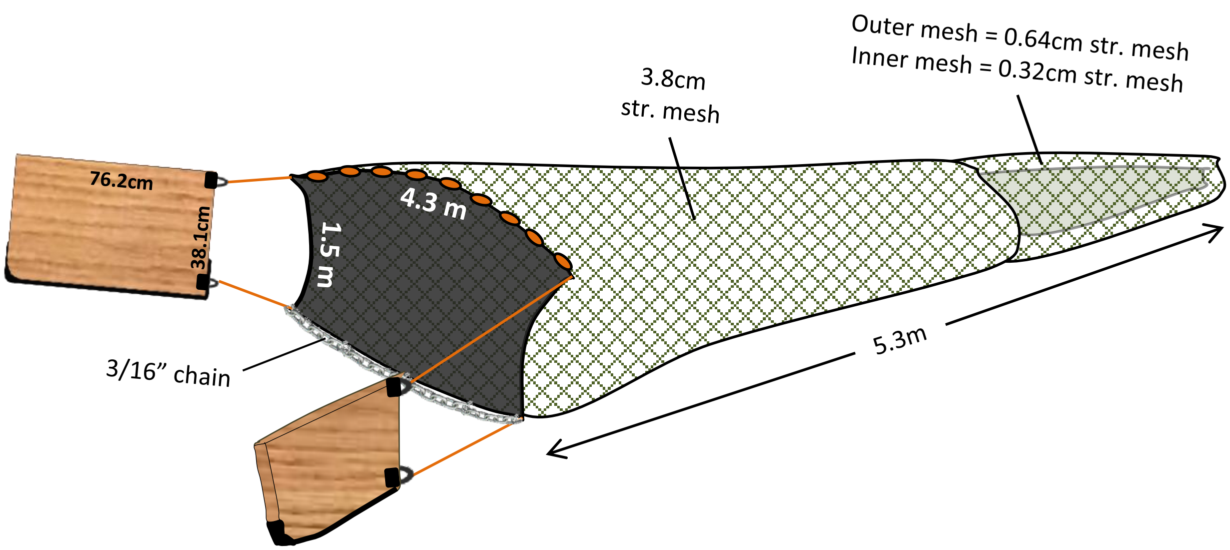


Figure II.22. Otter trawl net dimensions attached to plywood doors.

The lampara net used to sample channel habitat is described in the "Littoral Habitat Gear Comparison" section of this paper (Figure II.10).

Sampling Procedure

All three gear types were deployed at the same time at each sampling station (Figure II.23). Since this study encroached on UC Davis' routine otter trawl sampling survey, the UC Davis project chose their tow direction first to ensure their long standing data set was not compromised. Typically, the lampara sampled in between the two towing gears, where both gears towed away from the lampara net (Figure II.23).

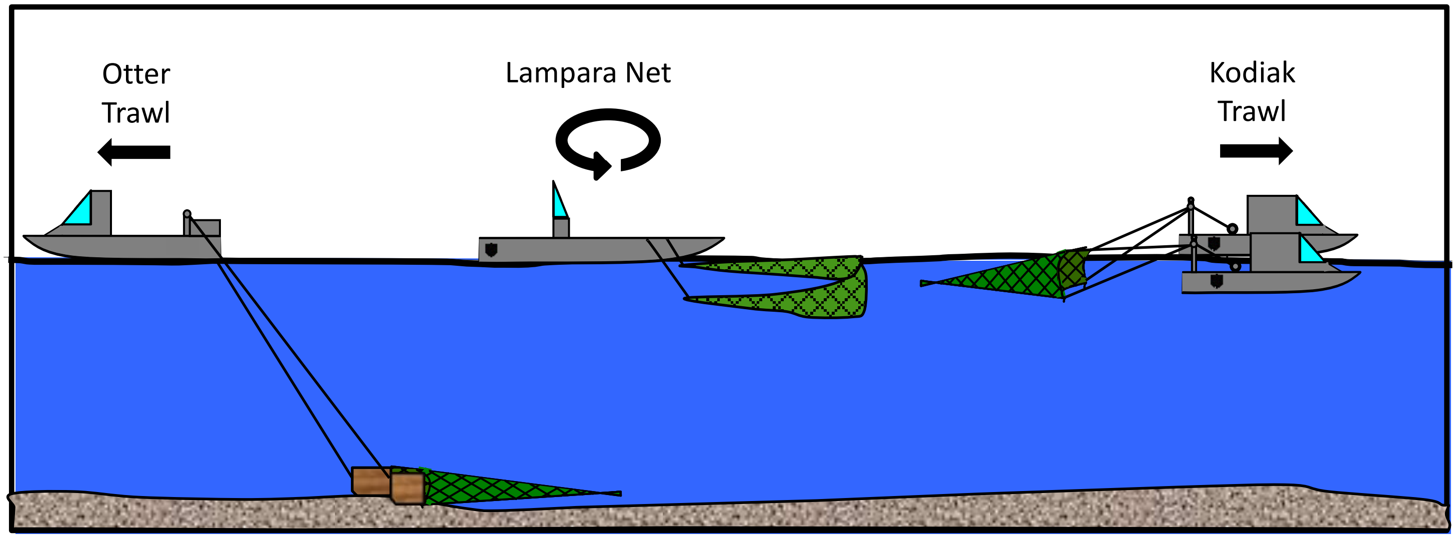


Figure II.23. Depiction of how gears were deployed and each gear's towing direction at a sampling station.

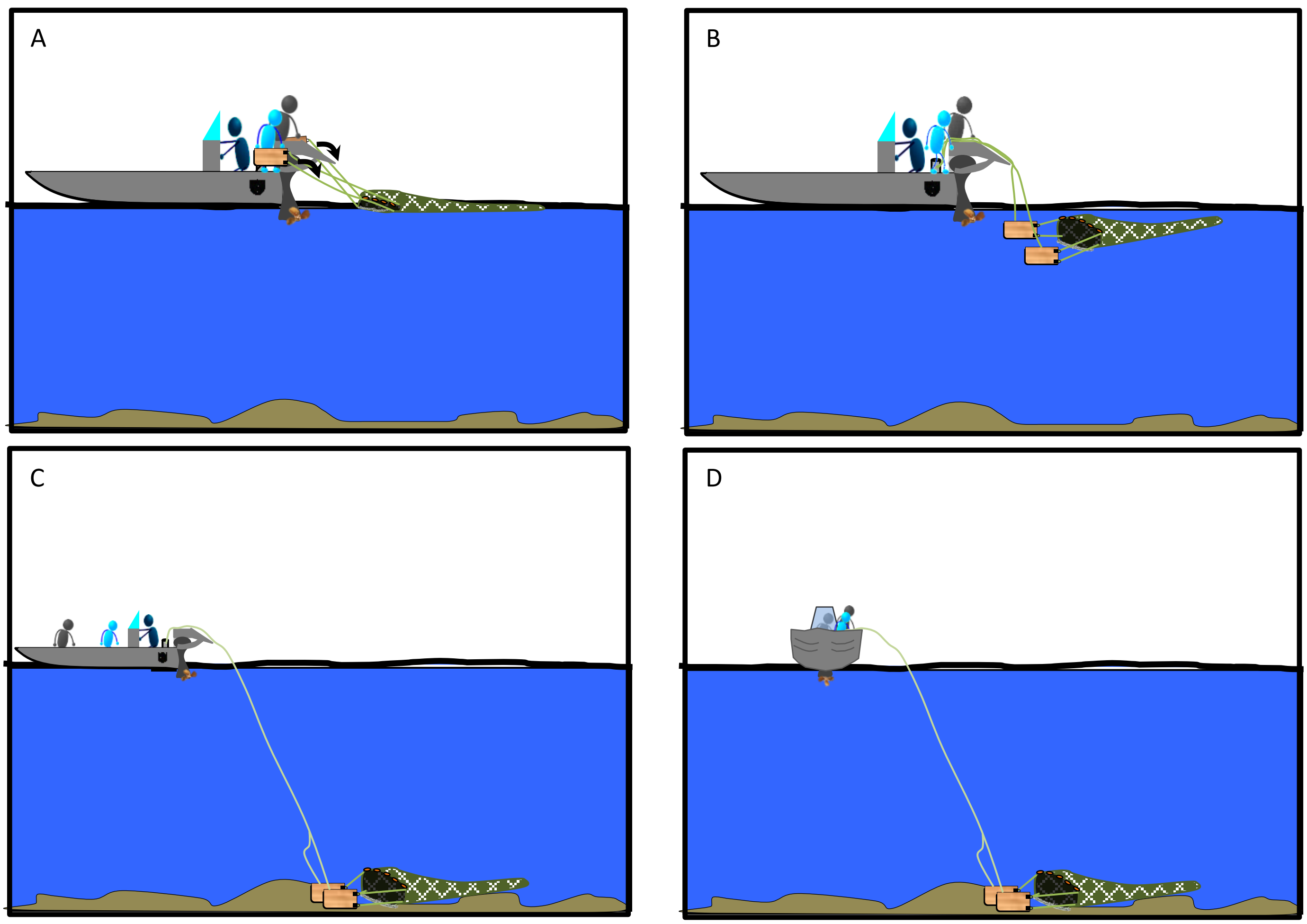


Figure II.24. Deployment of an otter trawl.

The otter trawl was deployed from an aluminum boat with a custom made trawl deck. At each trawling site the net was tossed off the stern of the boat (Figure II.24A). Once the net was deployed, two crew members each grabbed an otter trawl board and simultaneously dropped them off the stern of the boat (Figure II.24B). The tow began once the gear was fully deployed. The gear was towed for five minutes and then the otter trawl was retrieved on the bow of the boat (Figures II.24 C & D). The cod end of the gear was opened and fish were dumped into a tray filled with water. Thirty individuals of each fish species were measured using standard length to the nearest mm and all remaining fish were plus counted.

Since no flowmeter was deployed, the water volume sampled was calculated using an estimated mouth opening multiplied by distance traveled for all tows (J. Montgomery, UC Davis, pers. comm., August 3, 2016). Fish CPUE was calculated using the number of fish caught per volume water sampled (standardized to 10,000 m^3) using the following equation: (fish catch/1189m^3)*10000.

The lampara net was deployed off an aluminum boat. At each sampling station, the tip of the wing was tossed into the water attached to a buoy and sea anchor (Figure II.25A). Crewmembers deployed the net from the bow of the boat as the boat moved in a circular fashion back to the buoy and sea anchor (Figure II.25B). One crewmember then brought the buoy and sea anchor onboard and hooked both ends of the net onto the front cleat. The boat then went backwards and caused the net to impinge on itself to prevent fish from escaping through the bottom of the net (Figure II.25C). Once the net was "folded in half", each crewmember grabbed one side of the net and brought it onboard (Figure II.25D). Once the cod end was reached, it was placed in a tub filled with water. Thirty individuals of each fish species were measured using fork length to the nearest mm and all remaining fish were plus counted

Since the net width of lampara net could not be recorded when set, the water volume was estimated based on station depth. If a site's depth exceeded 3.0m, the estimated volume was based on 3.0m, which represents the maximum net depth. Fish CPUE was calculated using the number of fish caught per volume water sampled (standardized to 10,000 m^3) using the following equation: (fish catch/volume sampled)*10000.

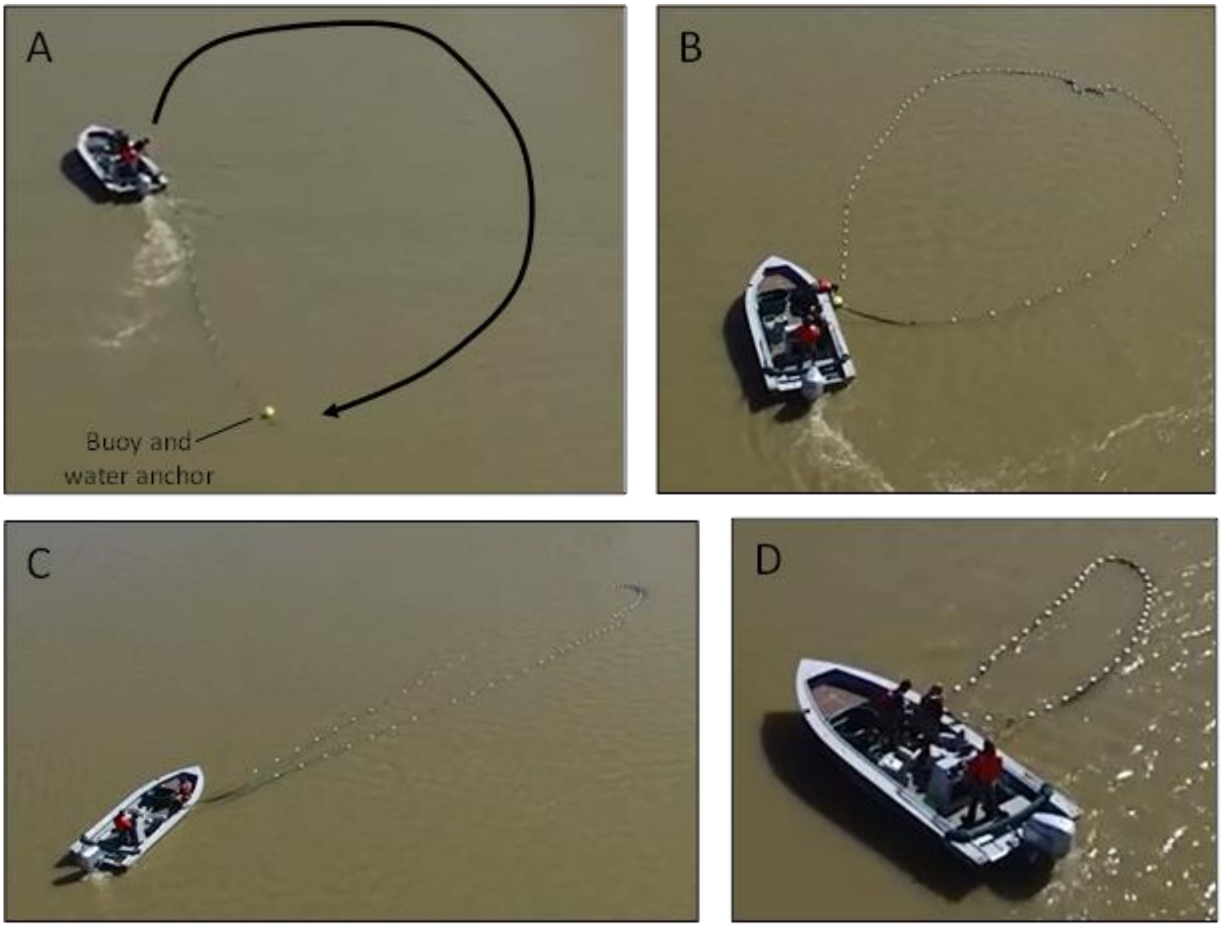


Figure II.25. Overhead depiction of lampara net deployment in channels and open water habitat. Still photos taken from a video near Liberty Island (C. Sloop, CDFW 2016).

The Kodiak trawl was deployed off an aluminum boat and towed in unison with a fiberglass boat. At each sampling site, the fiberglass boat (hereafter referred to as the “chase boat”) drove up to the side of the aluminum boat (hereafter referred to as the “net boat”) and tied the lazy line with an attached buoy to the bow of the chase boat (Figure II.26A). The chase boat backed up and deployed the net up to the aluminum spreader bars (Figure II.26B). Each spreader bar was deployed into the water by crewmembers and then the chase boat began to back up again. Once the bridles and ¾ of towing line were deployed, the net boat pivoted 90° into towing position deploying the rest of the towing line (Figure II.26C). Keeping the towing line taught, the chase boat came alongside the net boat and was handed a towing line. Once the two boats were approximately 4.6m apart, the five minute tow began and the flowmeter was deployed off the side of the net boat (Figure II.26D). Upon reaching five minutes, the flowmeter was retrieved and both boats came together. The chase boat handed the trawl line back to the net boat and moved out of the way. The net boat pivoted 90° and was perpendicular to the net (Figure II.26E). The towing lines and net were brought back onboard by the crewmembers. Thirty individuals of each fish species were measured using fork length to the nearest mm and all remaining fish were plus counted.

Fish CPUE was calculated using the number of fish caught per volume water sampled (standardized to 10,000 m^3) using the following equation: (fish catch/water volume sampled)*10000, where water volume = mouth opening of the net (m^2) * calibration factor of the flow meter * difference in flow meter counts from start to finish of tow. Due to the constriction of the channel, we assumed the net mouth to be 75% open.

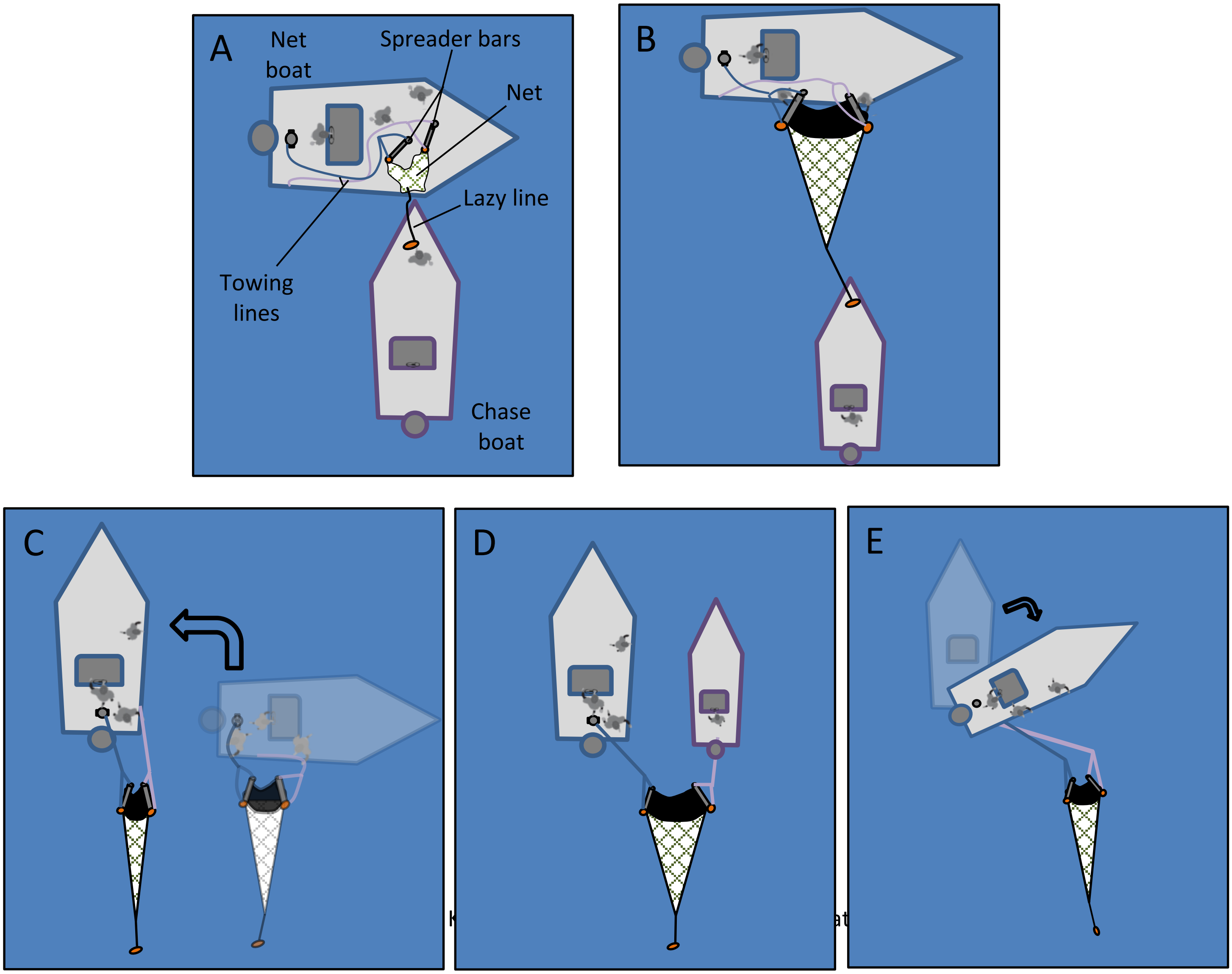


Figure II.26. Overhead view of how the Kodiak trawl is deployed using two boats.

Analysis

Four components of data were compared among the two gear types: fish CPUE, fork lengths, species composition, and diversity.

Each gear type's CPUE was summed across all fish species for each tow and then tested for normality using a Wilks-Shapiro test. The results of the Wilks-Shapiro test suggested the data were not normally distributed. A Kruskal-Wallace test was run in R software comparing total tow CPUE for all three gear types. Due to the low catch observed in the Kodiak trawl, it was dropped from further analysis and only the otter trawl and lampara net were compared. A separate CPUE comparison was made between the otter trawl and lampara net with a Wilcoxon rank-sum test which included additional samples in February (n = 1) and June (n = 6) that were not sampled by the Kodiak Trawl.

Because UC Davis measures fish by standard length, and CDFW measures fish by fork length, the otter trawl fish lengths were converted from standard length to fork length using a suite of equations taken from journal articles, master thesis papers, fishbase.org, and in house regressions (Appendix C). Lengths between 12 - 179mm were pooled into 4mm groups for both gear types and compared with a Kolmogorov-Smirnov (K-S) test using Past 3 software (Hammer et al. 2001). This size range was chosen because the otter trawl length frequency catch > 179mm appeared to be sporadic and not representative of targeted fish size ranges.

Each sampling site's fish species CPUE was transformed into a percent catch based on the total CPUE of each gear type. Using the percent catch of each species caught per tow, a one-way analysis of similarity (ANOSIM, Clarke 1993) was run to test whether fish composition differences occurred between the otter trawl and lampara net from January through March. An additional ANOSIM test was run using only sites with depths ≤ 3m. This test was conducted to get a better comparison between both gears as the lampara would be sampling the bottom. Sample rarefaction curves were generated using presence-absence data for each gear type to estimate species richness based on the number of sites sampled (Colwell et al. 2004). Rarefaction curves can determine the optimal number of samples to take before species accumulation becomes dismal. Shannon-Wiener indices were generated for both gear types using each species' total CPUE from each sample. Diversity indices were tested for normality using a Wilks-Shapiro test and compared using a Mann-Whitney U test.

Results

A total of 699 fish and 21 fish species were collected with fork lengths ranging from 9 – 335mm from 16 Kodiak trawls, 23 otter trawls, and 23 lampara hauls (Table II.5). The Kodiak trawl caught the fewest fish species and the otter trawl caught the most. Approximately 78% of the total Kodiak trawl catch was composed of Threadfin Shad from one tow (Table II.5). Eighty-three percent of the otter trawl catch was composed of Black Crappie, Bluegill, Redear Sunfish, Striped Bass, and Wakasagi (Table II.5). Eighty-one percent of the lampara catch was composed of Mississippi Silverside, Redear Sunfish, and Threadfin Shad. The Kodiak trawl CPUE was significantly lower than the otter trawl and lampara net ($p < 0.01$). The CPUE did not differ between the otter trawl and lampara net ($p = 0.17$).

Table II.5. Catch, CPUE, and fork length ranges of every species caught by each gear type. Abbreviations next to fish names represent abundant fish caught presented in Figure II.28. Please note that Wakasagi fork lengths (FL) were estimated based on a few that were measured. Unidentified fish represent fish that could not be identified in the field or lab because the fish was too mangled.

Fish Species	Kodiak Trawl (n = 16)			Otter Trawl (n = 23)			Lampara Net (n = 23)		
	Catch	CPUE	FL Range (mm)	Catch	CPUE	FL Range (mm)	Catch	CPUE	FL Range (mm)
Bigscale Logperch				4	33.6	34 - 116	2	38.0	14 & 21
Black Bullhead				2	16.8	162 & 208			
Black Crappie (BLACRA)				50	420.5	73 - 287			
Bluegill (BLUEGI)				31	260.7	44 - 215	2	28.4	36 & 90
Brown Bullhead				1	8.4	152			
Centrarchid spp.				2	16.8	31 & 33			
Golden Shiner (GOLSHI)	2	22.7	102 & 148	8	67.3	142 - 212	12	182.4	54 - 140
Hitch				1	8.4	316			
Largemouth Bass				6	50.5	120 - 302	2	88.5	134 & 335
Mississippi Silverside (MISSIL)	6	52.0	51 - 83				60	964.6	16 - 101
Prickly Sculpin				14	117.7	15 - 154	2	32.4	75 & 85
Redear (REDEAR)	2	19.8	170 & 229	31	260.7	18 - 263	12	462.7	47 - 228
Sacramento Pikeminnow							1	15.0	80
Shimofuri Goby				4	33.6	21 - 80			
Striped Bass (STRBAS)				86	723.3	9 - 258	16	214.8	13 - 38
Threadfin Shad (THRSHA)	37	419.9	60 - 88	3	25.2	102 - 144	207	2892	16 - 144
Tridentiger Sspp.							11	147.7	12-22
Tule Perch				1	8.4	131	1	19.0	63
Unidentified Fish				1	8.4		13	185.6	N.A.
Wakasagi (WAKASA)				58	487.8	~60 - 65			
Warmouth				1	8.4	53			
White Catfish				5	42.1	216 - 318	1	13.4	285
White Crappie				1	8.4	189	1	16.6	97
Total	47	514.4	N.A.	310	2607.2	N.A.	342	5301.1	N.A.

Fish size varied in the otter trawl and was composed of multiple year classes for many fish species, while the lampara net was mainly composed of young-of-year fishes. Fork length distribution differed between the otter trawl and lampara net (p = 0.03). Approximately 85% of the fish caught by the otter trawl ranged from 14 – 177mm and 96% of fish caught by the lampara net ranged from 12 – 94 mm (Figure II.27). Two lampara hauls caught a total of 185 Threadfin Shad and mainly composed of fish sizes ranging from 16 - 40mm (Figure II.27). The otter trawl caught a wider range of fish lengths for demersal fish species (BLACRA, BLUEGI, PRISCU, READEAR, and STRABAS) and the lampara net caught a wider range of fish lengths for pelagic species (GOLSHI, MISSIL, and THRSHA) (Figure II.28).

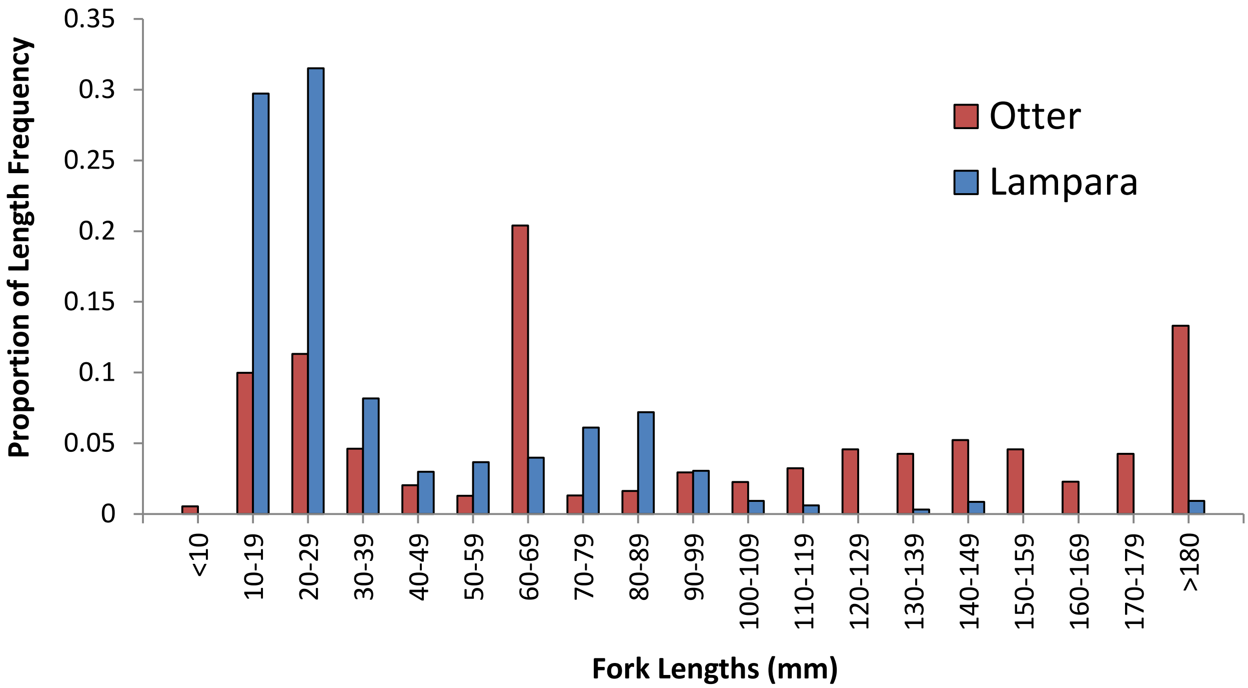


Figure II.27. The proportion of fork length frequency caught by each gear type. Fish less than 12mm and greater than 179mm were not used for length comparisons between gear types.

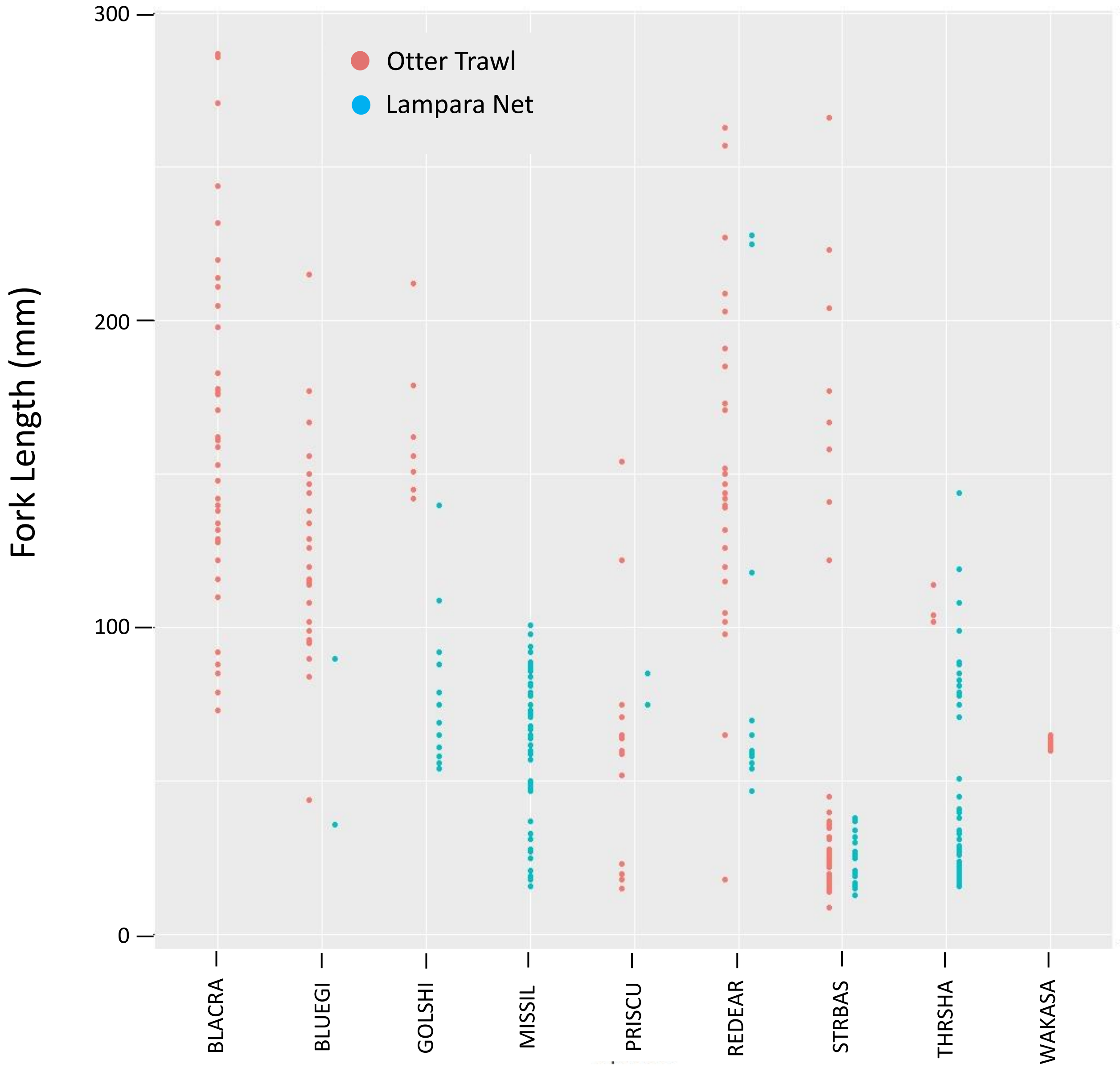


Figure II.28. Measured fork length ranges of 9 most abundant species caught by the otter trawl and lampara net. Each dot represents an individual fish. Species codes are listed in Table II.5.

More species were consistently caught with the otter trawl than the lampara net and fish compositions between gear types were significantly different ($R = 0.22$, $p < 0.001$). Similarly, at sites ($n = 8$) where the lampara was sampling along the floor, fish composition differed between the two gear types ($R = 0.22$, $p = 0.004$). This is consistent with the generated sample rarefaction curves which show higher fish species detection for the otter trawl (Figure II.29). The otter trawl catch consisted of more demersal fishes such as gobies, catfish, and sunfish, while the lampara catch consisted of pelagic fish species such as silversides and shad. Fish species diversity differed between the gear types ($z = -3.5185$, $p < 0.001$) and was higher for the otter trawl (Table II.6).

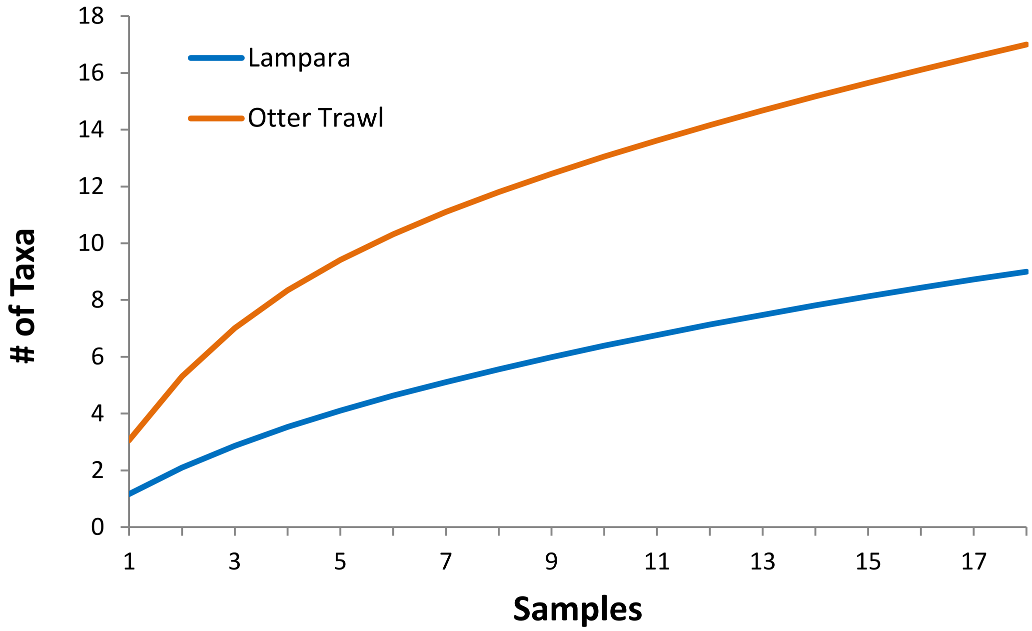


Figure II.29. Sample rarefaction curves for the otter trawl and lampara net

Table II.6. Mean Shannon-Wiener diversity index and standard error values.

Gear	Mean Diversity Index	SE
Lampara	0.34	0.10
Otter Trawl	0.96	0.12

Discussion

The Kodiak trawl did not catch as many fish as we initially expected. This gear type is used by long-term monitoring surveys in wider channels and has been shown to be very effective in catching pelagic fish species. However, in smaller channels, this gear type did not perform as well as the otter trawl and lampara net. Since the boats were only about 11m across from one another when Kodiak trawling, the net mouth area was smaller, affecting fish catch. We also suspect that the small distance between boats when trawling scared and pushed fish ahead or to the side of the boat bow. As mentioned previously in the larval fish section discussion, boat disturbance may influence the number and species of fish caught. Tiffan et al. (2010) suggests that pelagic fish near the surface of the water cannot be effectively sampled due to boat avoidance.

The smaller otter trawl net caught more fish than the Kodiak trawl. Since the otter trawl fishes the bottom of the channel, it may be less affected by boat disturbance as site depth increases. The lampara net sampled a smaller volume of water than the Kodiak and otter trawl, but had the overall highest abundance of fish. We suspect that the encircling deployment of the lampara net was effective in capturing smaller pelagic fishes.

The lampara caught approximately 39% fewer species than the otter trawl. Higher species composition in the otter trawl may be attributed to a higher amount of water volume sampled (Figure II.30A) and the way the two gears sample (Figure II.30B). Studies have shown that sampling a larger volume of water volume increases fish species detection (DeLacy and English 1954, Riha et al. 2008, Wantiez 1996). Fish species detection also may differ just by the way the two gears sample fish. The encircling deployment of lampara net likely scares away bigger or faster fish species before the bottom of the net is sealed off. In contrast, the otter trawl may retain larger or faster fish species because the gear is towed continuously for 5 minutes. Although the otter trawl caught more fish species, the otter trawl and lampara net caught representative fish species (demersal vs pelagic) based on the layer of water each gear sampled.

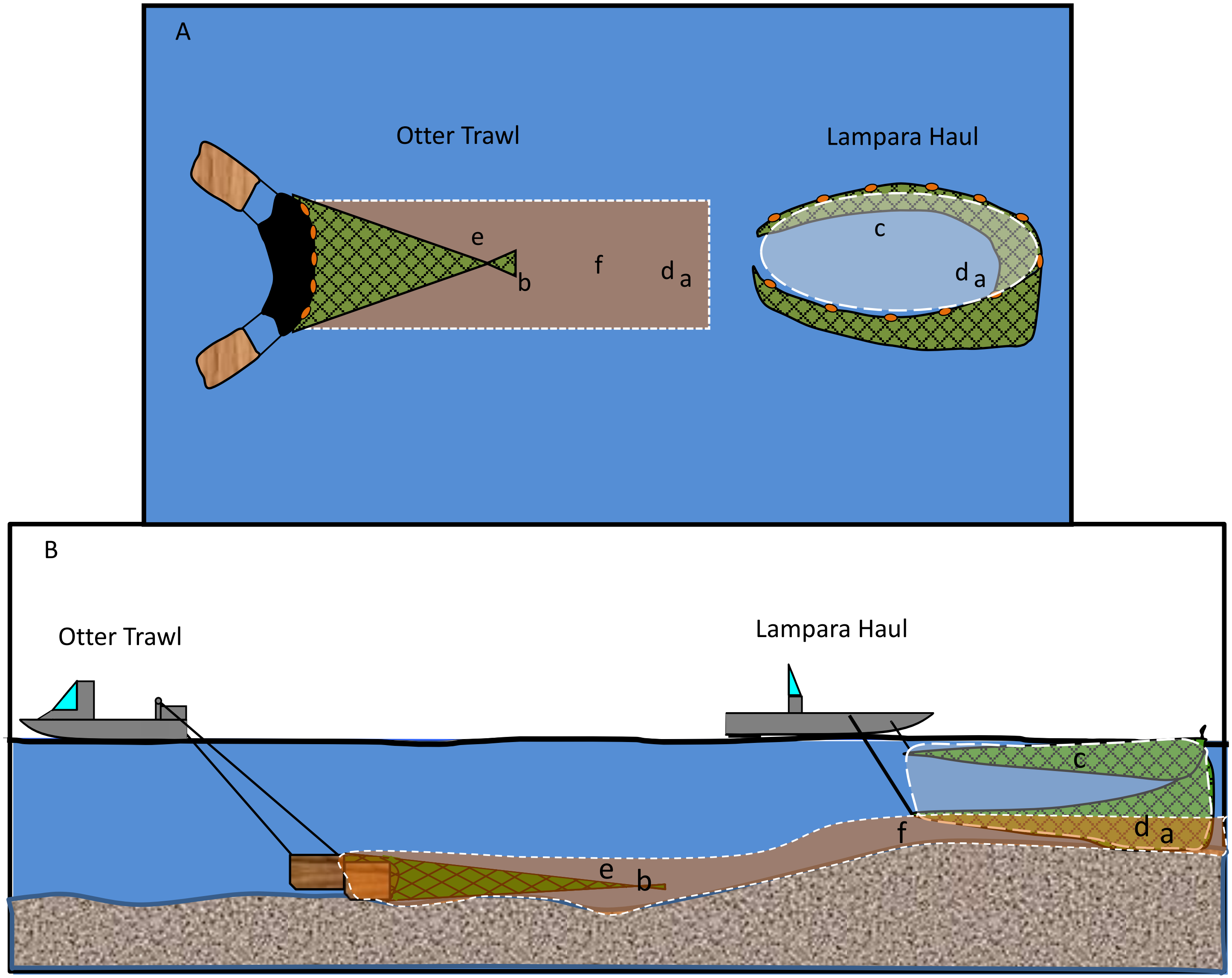


Figure II.30. A) Overhead two-dimensional mock diagram of the otter trawl and lampara net water volume sampled (represented by the translucent orange or white area surrounded by white dotted line). **B)** Side view two-dimensional mock diagram of the otter trawl and lampara net water volume sampled (represented by the translucent orange or white area surrounded by white dotted line). Fish species caught by each gear is represented by a letter (please note that in this example, species “b”, “e”, and “f” were only detected by the otter trawl and species “c” was only detected by the lampara haul).

Based on the results of this study, we are recommending the otter trawl to sample tidal channel and open water habitats of tidal wetlands. Although the otter trawl mainly catches demersal non-native fishes, this information is important as it provides data relating to the potential competitors and predators of target species Delta Smelt, Longfin Smelt, and Chinook Salmon. Since many of the restored wetlands will be shallow, we expect the otter trawl will be able to sample a majority of the water column and catch many fish species. In addition, the FRP otter trawl net has the same net dimensions and mesh sizes as the one used by the UC Davis Suisun Marsh and North Delta Arc programs and allows data to be comparable to their surveys. However, if pelagic fish are not effectively sampled using the otter trawl, the lampara net may be deployed to sample these fishes.

Conclusion

Comparing gear types in various habitats was a useful tool in deciding which method provides representative fish catch, lengths, and composition at each sampling site. All gear types are inherently biased and no gear type can effectively sample all habitat types. The gear types recommended for sampling tidal wetlands represent those that catch target species and their potential predators and competitors. The gear types recommended for tidal wetland fish monitoring are:

- Larval fish – Surface trawl
- Juvenile littoral fish habitat - Beach seine
- Juvenile open water/channel habitat – Otter trawl

Although the lampara net was not recommended for monitoring tidal wetlands, this method may be useful as a supplemental monitoring technique for at-risk pelagic species. Although few at-risk fish species were caught in the littoral habitat and no at-risk fish species were caught in channel habitat, we suspect that they are susceptible to the gear as Chinook Salmon and Delta Smelt were lampara net targets in other studies (Naughton et al. 2010; Tiffan et al. 2010; Afentoulis et al. 2013).

A potential advantage the lampara net has over other gear types is possibly reducing Delta Smelt mortality. The lampara net is used by UC Davis Fish Culture Facilities to collect Delta Smelt brood stock and results in observed average Delta Smelt survival rates of 85% after 72 hours of capture (G. Tigan, UC Davis, pers. comm., November 9, 2015). Beeman et al. (2013) collected 142 Chinook Salmon and found an 89.8% post tagging survival rate of Chinook Salmon after being caught by the lampara net. However, high mortality rates of Chinook Salmon caught in the lampara net were observed in the Snake River Reservoir in 2009 and were thought to be a combination of descaling from the lampara net and holding pen (Naughton et al. 2010). In order to decrease mortality rates due to net stress, handling, and abrasion, retrieval methods should be adjusted to minimize injury to fragile fish species.

The gear types recommended in this paper will be used to begin pre-project monitoring outside of future tidal wetland systems. Initially, comparisons between the fyke netting and electrofishing, and gill netting and electrofishing were intended, but did not occur due to logistical constraints. These methods still need to be tested to determine if they should be recommended for tidal wetland sampling. Other aspects of gear performance, such as gear efficiency and species-specific net avoidance, should be studied to determine sampling error. Gear efficiency studies can provide inferences on fish abundance populations and assemblage structures (Herzog et al. 2011; Perry et al. 2016). Lastly, littoral fish abundance and assemblage in vegetation was not sampled due to the vast amount of effort required of vegetation removal from the net. Based on data from one lampara seine in vegetation, it may be worth the effort to spend a day sampling littoral vegetated areas to describe the fish community within that habitat.

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Appendix A.

List of all macroinvertebrate taxa identified in our samples and total number of each taxon identified.

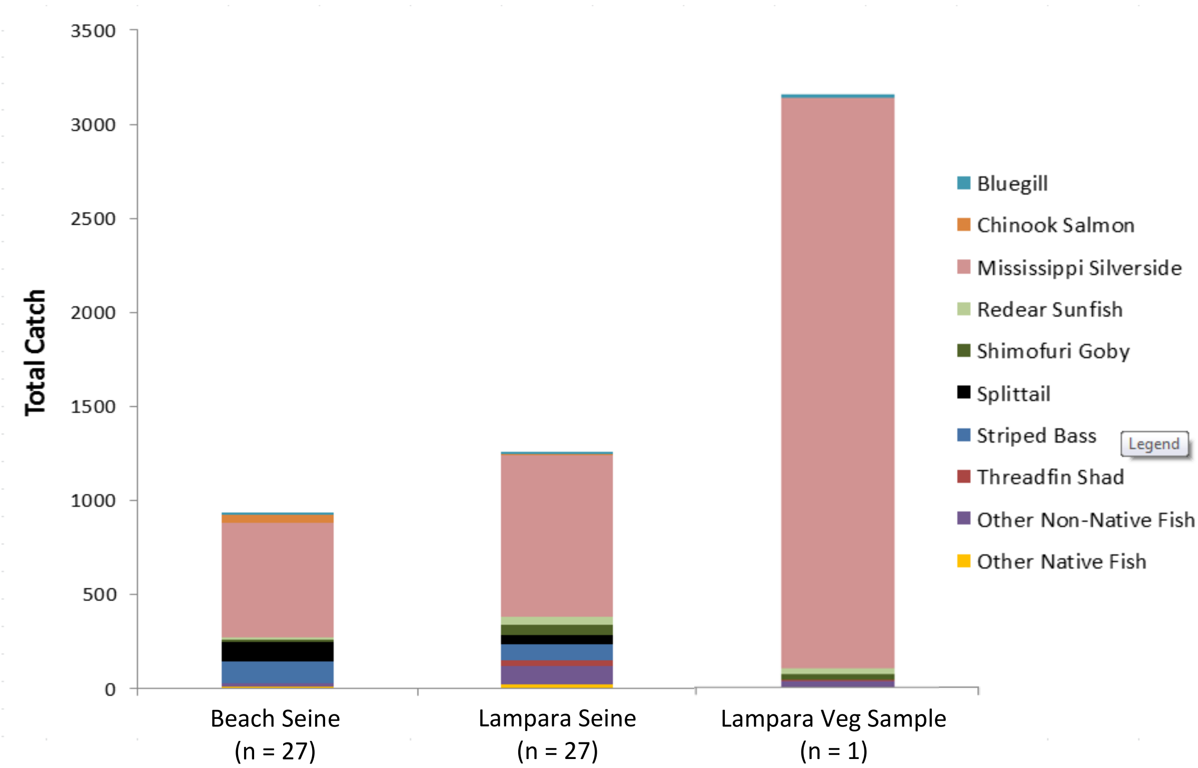
Analysis Group	Phylum	Class	Order	Family	Genus	Total Count
Acari	Arthropoda	Arachnida	Hydracarina	various		434
Amphipoda	Arthropoda	Malacostraca	Amphipoda	Corophiidae	Americorophium	641
Amphipoda	Arthropoda	Malacostraca	Amphipoda	Crangonycitidae	Crangonyx	3230
Amphipoda	Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammarus	279
Amphipoda	Arthropoda	Malacostraca	Amphipoda	Hyalellidae	Hyalella	5318
Amphipoda	Arthropoda	Malacostraca	Amphipoda	unkown/juvenile		1596
Annelida	Annelida	Hirudinea	various			160
Annelida	Annelida	Oligocheata	various			3041
Annelida	Annelida	Polychaeta	Phyllodocida	Nereididae	Hediste	2
Bivalvia	Mollusca	Bivalvia	other			32
Bivalvia	Mollusca	Bivalvia	Veneroida	Corbiculidae	Corbicula	196
Cladocera	Arthropoda	Branchiopoda	Cladocera	various		11778
Coleoptera	Arthropoda	Insecta	Coleoptera	Curculionidae	various	35
Coleoptera	Arthropoda	Insecta	Coleoptera	Dytiscidae	various	64
Coleoptera	Arthropod	Insecta	Coleoptera	Elmidae	various	24
Coleoptera	Arthropoda	Insecta	Coleoptera	Elmidae	various	1
Coleoptera	Arthropoda	Insecta	Coleoptera	Gyrinidae	various	16
Coleoptera	Arthropod	Insecta	Coleoptera	Hydrophilidae	various	9
Coleoptera	Arthropoda	Insecta	Coleoptera	Hydrophilide	various	4
Coleoptera	Arthropoda	Insecta	Coleoptera	Noteridae	various	3
Coleoptera	Arthropoda	Insecta	Coleoptera	Staphylinidae	various	64
Coleoptera	Arthropoda	Insecta	Coleoptera	unkown		17
Collembola	Arthropoda	Collembola	various			2525
Copepoda	Arthropoda	Copepoda	Calanoida	various		9334
Copepoda	Arthropoda	Copepoda	Cyclopodia	various		1405
Copepoda	Arthropoda	Copepoda	Harpacticoida	various		1
Copepoda	Arthropoda	Copepoda	unknown			3
Decapoda	Arthropoda	Malacostraca	Decapoda	Astacidae	Pacifastacus	2
Decapoda	Arthropoda	Malacostraca	Decapoda	Caridae	Palaemon	1
Decapoda	Arthropoda	Malacostraca	Decapoda	Palaemonidae	Exopalaemon	1
Decapoda	Arthropoda	Malacostraca	Decapoda	Palaemonidae	Palaemonetes	6
Decapoda	Arthropoda	Malacostraca	Decapoda	unkown		42
Diptera	Arthropoda	Insecta	Diptera	Ceratopogonidae		62
Diptera	Arthropoda	Insecta	Diptera	Chironomidae		3373
Diptera	Arthropoda	Insecta	Diptera	Dolichopodidae		2
Diptera	Arthropoda	Insecta	Diptera	Ephydridae		1
Diptera	Arthropoda	Insecta	Diptera	Psychodidae		3
Diptera	Arthropoda	Insecta	Diptera	Tabanidae		9

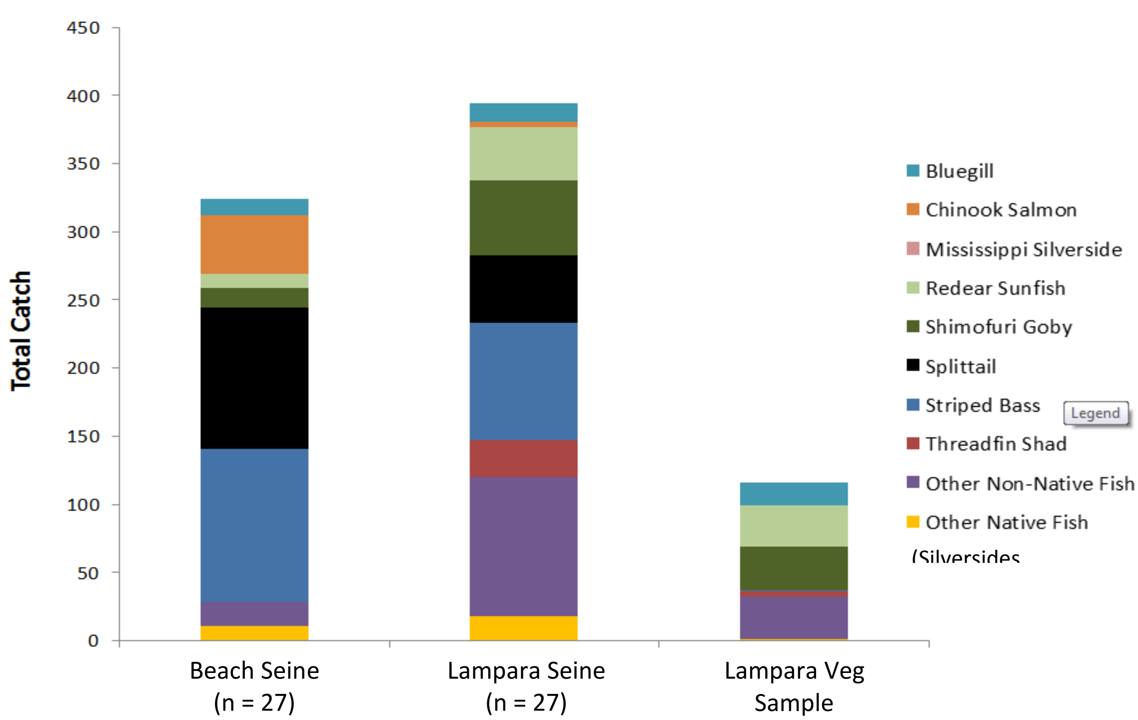
Analysis Group	Phylum	Class	Order	Family	Genus	Total Count
Diptera	Arthropoda	Insecta	Diptera	Tipulidae		13
Diptera	Arthropoda	Insecta	Diptera	unkown adults		968
Ephemeroptera	Arthropoda	Insecta	Ephemeroptera	Baetidae		3
Ephemeroptera	Arthropoda	Insecta	Ephemeroptera	Caenidae		7
Ephemeroptera	Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes	3
Ephemeroptera	Arthropoda	Insecta	Ephemeroptera	unkown		7
Gastropoda	Mollusca	Gastopoda	Caenogastropoda	Lythoglyphidae	Fluminicola	7353
Gastropoda	Mollusca	Gastropoda	Caenogastropoda	Thiaridae	Melanoides	18
Gastropoda	Mollusca	Gastropoda	Heterobranchia	Lymnaeidae	Lymnaea	68
Gastropoda	Mollusca	Gastropoda	Heterobranchia	Physidae	Physa	683
Gastropoda	Mollusca	Gastropoda	Heterobranchia	Planorbidae	Gyraulus	649
Gastropoda	Mollusca	Gastropoda	Heterobranchia	Planorbidae	other	13
Gastropoda	Mollusca	Gastropoda	Limnophila	Ancylus	Ferrissia	63
Gastropoda	Mollusca	Gastropoda	unkown			61
Hemiptera	Arthropoda	Insecta	Hemiptera	Belostomatidae		2
Hemiptera	Arthropoda	Insecta	Hemiptera	Corixidae		1140
Hemiptera	Arthropoda	Insecta	Hemiptera	Mesoveliidae		14
Hemiptera	Arthropoda	Insecta	Hemiptera	Vellidae		1
Hemiptera	Arthropoda	Insecta	Hemiptera	unknown		15
Isopoda	Arthropoda	Malacostraca	Isopoda	Asellidae	Asellus	19
Isopoda	Arthropoda	Malacostraca	Isopoda	Sphaeromatidae	Gnorimosphaeroma	4590
Isopoda	Arthropoda	Malacostraca	Isopoda	unkown		240
Lepidoptera	Arthropoda	Insecta	Lepidoptera	unknown		1
Mysidacea	Arthropoda	Malacostraca	Mysida	Mysidae	Neomysis	279
Nematoda	Nematoda	various				29
Nemertea	Nemertea	Enopla	Monostilifera	Tetrastemmatidae	Prostoma	15
Odonata	Arthropoda	Insecta	Odonata	Aeshnidae	various	1
Odonata	Arthropoda	Insecta	Odonata	Coenagrionidae	various	244
Odonata	Arthropoda	Insecta	Odonata	Libellulidae	various	7
Odonata	Arthropoda	Insecta	Odonata	unkown		2
Ostracoda	Arthropoda	Ostacoda	various			178
Platyhelmenthes	Platyhelminthes	Rhabditophora	Tricladida	Dugesiidae	Girardia	729
Tanaidacea	Arthropoda	Malacostraca	Tanaidacea	various		12
Trichoptera	Arthropoda	Insecta	Trichoptera	Hydroptilidae	various	237
Trichoptera	Arthropoda	Insecta	Trichoptera	Polycentripodidae	various	1
Trichoptera	Arthropoda	Insecta	Trichoptera	unknown		8
terrestrial	Arthropoda	Arachnida	Araneae	various		99
terrestrial	Arthropoda	Insecta	Coleoptera	various		91
terrestrial	Arthropoda	Insecta	Dermaptera	various		1
terrestrial	Arthropoda	Insecta	Hemiptera	Aphididae		394

terrestrial	Arhtropoda	Insecta	Hymenoptera	Formicidae		58
Analysis Group	**Phylum**	**Class**	**Order**	**Family**	**Genus**	**Total Count**
terrestrial	Arthropoda	Insecta	Hymenoptera	various		65
terrestrial	Arthropoda	Insecta	Orthoptera	various		1
terrestrial	Arthropoda	Insecta	Thysanoptera	various		165
other	Mollusca	Gastropoda	unknown			4
other	Cnidaria	Hydrozoa	Hydrida	Hydridae	Hydra	96
other	Arthropoda	Insecta	unknown			16
other	Arthropoda	Insecta	various			5
other	Arthropoda	Malacostraca	unknown			1
other	Tardigrades	unknown				1

Appendix B.

Littoral total fish catch of the beach seine, lampara, and lampara in vegetation. Top graph reflects the total catch and bottom graph reflects the total catch with Mississippi Silversides removed.





Appendix C.

Fish standard length conversions to fork length or total length.

Common Name	Standard Length to Fork Length Conversion Equation	Standard Length to Total Length Conversion Equation	Fish Measured In Field	Fish Measured After Preservation	Source	Comments
Bigscale Logperch		(SL * 1.2095) - 4.614	x		Measurements from field by D. Contreras (n=7), unpublished CDFW data.	
Black Bullhead	SL * 1.156				From Fishbase.org	
Black Crappie	SL * 1.221				From Fishbase.org	
Bluegill	(SL * 1.225)/1.024				From Fishbase.org	
Brown Bullhead	(SL * 1.135)/1.008				From Fishbase.org	
Centrarchid spp.	(SL * 1.225)/1.024					Used Bluegill As Surrogate
Golden Shiner	SL/0.896				From Fishbase.org	
Hitch	SL/0.896					Used Golden Shiner as a surrogate
Largemouth Bass	(SL/0.861) + 0.17				From Fishbase.org	
Prickly Sculpin	SL * 1.185				From Fishbase.org	
Redear	(SL * 1.225)/1.024				From Fishbase.org	Used Bluegill as a surrogate
Shimofuri Goby		(SL * 1.179) + 0.709	x		Measurements from field by D. Contreras (n=74), unpublished CDFW data	
Striped Bass	SL * 1.1317			x	Gartz, R. 2005. Standard and fork lengths of various fish species of the San Francisco Estuary. Unpublished CDFW data.	Fish preserved in isotonic salt solution
Threadfin Shad	SL * 1.0751			x	Gartz, R. 2005. Standard and fork lengths of various fish species of the San Francisco Estuary. Unpublished CDFW data.	Fish preserved in isotonic salt solution
Tule Perch	(SL * 1.179)/1.077				From Fishbase.org	

Common Name	Standard Length to Fork Length Conversion Equation	Standard Length to Total Length Conversion Equation	Fish Measured In Field	Fish Measured After Preservation	Source	Comments
Wakasagi	(SL * 1.088) + 0.2823				Gartz, R. 2005. Standard and fork lengths of various fish species of the San Francisco Estuary. Unpublished CDFW data.	Used Delta Smelt as a surrogate
Warmouth	SL * 1.179					
White Catfish	(SL*1.209)*0.907				From Fishbase.org	
White Crappie	(SL * 1.214)/1.034				From Fishbase.org	